DURABILITY OF CONCRETE BRIDGE DECKS IN NEW YORK STATE

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ABSTRACT

This investigation, initiated to assess the condition of concrete bridge decks on the State highway system, began with a statewide inspection of 334 structures constructed after 1950 and representing various designs and environments. Based on the results, 54 bridges were field tested and sampled for laboratory analyses to explain observed deterioration. Concurrently, repeated expression of interest by Department engineers in protective coatings for concrete decks prompted evaluation of existing coated bridges on the State system, and initiation of an experimental coating program.

Bituminous concrete wearing courses were found to be in good condition after an average 7 yr of service. Portland cement concrete wearing surfaces, averaging about 8 yr, exhibited various types and degrees of distress. Most prevalent were transverse and corner cracking in both air-entrained and non-air-entrained concrete decks. No significant difference in scaling was noted between concrete with or without specified air-entrainment, about 25 percent of each type exhibiting light to moderate distress. However, progressive scaling of non-air-entrained concrete wearing surfaces was suggested by a higher incidence of distress in decks more than 10 yr old. Significant progressive spalling of concrete pier caps and columns, both with and without air-entrainment, occurred on simple-span structures due to leakage through deck joints.

Field and laboratory test results helped in part to explain performance. For example, dynamic vibrations and structural type could not be correlated with observed crack patterns. However, cores removed from two-course portland cement concrete decks indicated that more severe cracking was associated with poor bond between courses. The generally similar scaling of concrete decks with and without air entrainment was attributed to marked variations in air content. While no evidence of distress was found in structural concrete decks covered by a bituminous concrete overlay, probably because of their young age when cored, high concentrations of deicing salt at the interface suggest the possibility of future deterioration.

Regarding protective coatings, none of the surface overlays lasted more than 2 to 3 yr. However, membrane materials placed as an interlayer between a bituminous concrete wearing surface and a structural concrete deck are performing satisfactorily. Silicone and distillate oil surface sealants did not appear to improve long-term durability of non-air-entrained concrete decks. While linseed oil applied to properly air-entrained concrete did not enhance durability, its use as inexpensive protection against random scaling associated with variations in air content is suggested by the favorable results of other investigators.

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Background

Deterioration of concrete bridge decks is one of the more complex problems in highway engineering. The widespread occurrence of this problem is suggested by the fact that several State highway agencies, including those of Missouri, Illinois, and Iowa, have conducted independent surveys of distressed bridges in their respective states (1). In addition, New Jersey, California, Texas, Maine, and other States have participated in a comprehensive bridge deck survey in cooperation with the Portland Cement Association and the Bureau of Public Roads (2).

Many explanations of concrete bridge deck deterioration have been advanced. A widely held opinion is that extensive use of de-icing chemicals is largely responsible for the problem. Others believe that deterioration is related more directly to insufficient air content, mix variations in concrete batches, use of excess water to ease concrete placement, and inadequate concrete curing. Defects such as cracking and spalling have been associated with poor design and construction practices, expansive aggregates, traffic density, and many other causes. It is generally agreed, however, that most deterioration results from a combination of adverse factors whose interaction is not clearly understood.

Bridge deck deterioration is of economic importance to bridge maintenance forces of all highway departments, including New York State. For example, in 1966, New York State was responsible for approximately 6,000 bridges located on or over State highways. Maintenance of these structures, in addition to new ones being built at an annual rate of approximately 300, involves large expenditures. These important considerations have created the impetus for this study.

Scope and Objectives

The study consisted of three parts:

1. A statewide condition survey of selected structures, to determine types and extent of bridge deck deterioration.

2. Detailed studies, including field and laboratory tests, to determine possible causes of deterioration.

3. A supplemental study to evaluate field performance of protective bridge deck coatings.

PART I: STATEWIDE CONDITION SURVEY

Selection of Bridges

Bridges were chosen from a total of approximately 2,800 built in New York State from 1950 through 1961. Structures were selected in each of the 10 State districts to represent a variety of climatic conditions, design types, and traffic densities. Also included were structures recommended for study by each District Bridge Engineer, because of unusually poor or excellent performance. Collectively, 334 bridges on primary, secondary, and interstate highway systems were inspected in 1963-64. A second survey including all but nine of the same structures was conducted in 1967. Its purpose was to update the study and determine if changes in bridge condition had occurred. Differences in the number of bridges inspected during the two surveys result from omission of structures either rehabilitated or resurfaced during the interim between surveys.

Figure 1 shows the geographical locations of the sampled bridges. The type of structural design of each is noted in Table 1. The predominant type of bridge construction in New York State during the 1950's and early 60's was the simple-span, composite I-beam deck. Consequently, this construction type comprised over 54 percent of the total bridge sample. Furthermore, all but one of the sampled bridges had a two-course deck, and approximately 60 percent of these consisted of a 2-1/2 in. bituminous concrete wearing surface on a 7-in. structural concrete slab. The remainder included a 4-in. portland cement concrete surface over a 7-in. slab.

Sampling was restricted to bridges constructed after 1950 because few maintenance and repair records were available to evaluate the performance of older structures. Moreover, many important design changes occurred after 1950. For example, in 1955 the 4-in. portland cement concrete (PCC) wearing surface used in the two course bridge deck was substituted with a 2-1/2 in. bituminous concrete (BC) wearing surface. Later, in 1957, New York State Specifications were revised to require air-entrained concrete in all bridge construction. After 1950, many new bridge designs included prestressed concrete box beams, "T" beams and I-beam construction. It was concluded therefore, that a sample representing bridges constructed during this period would be most desirable for study.

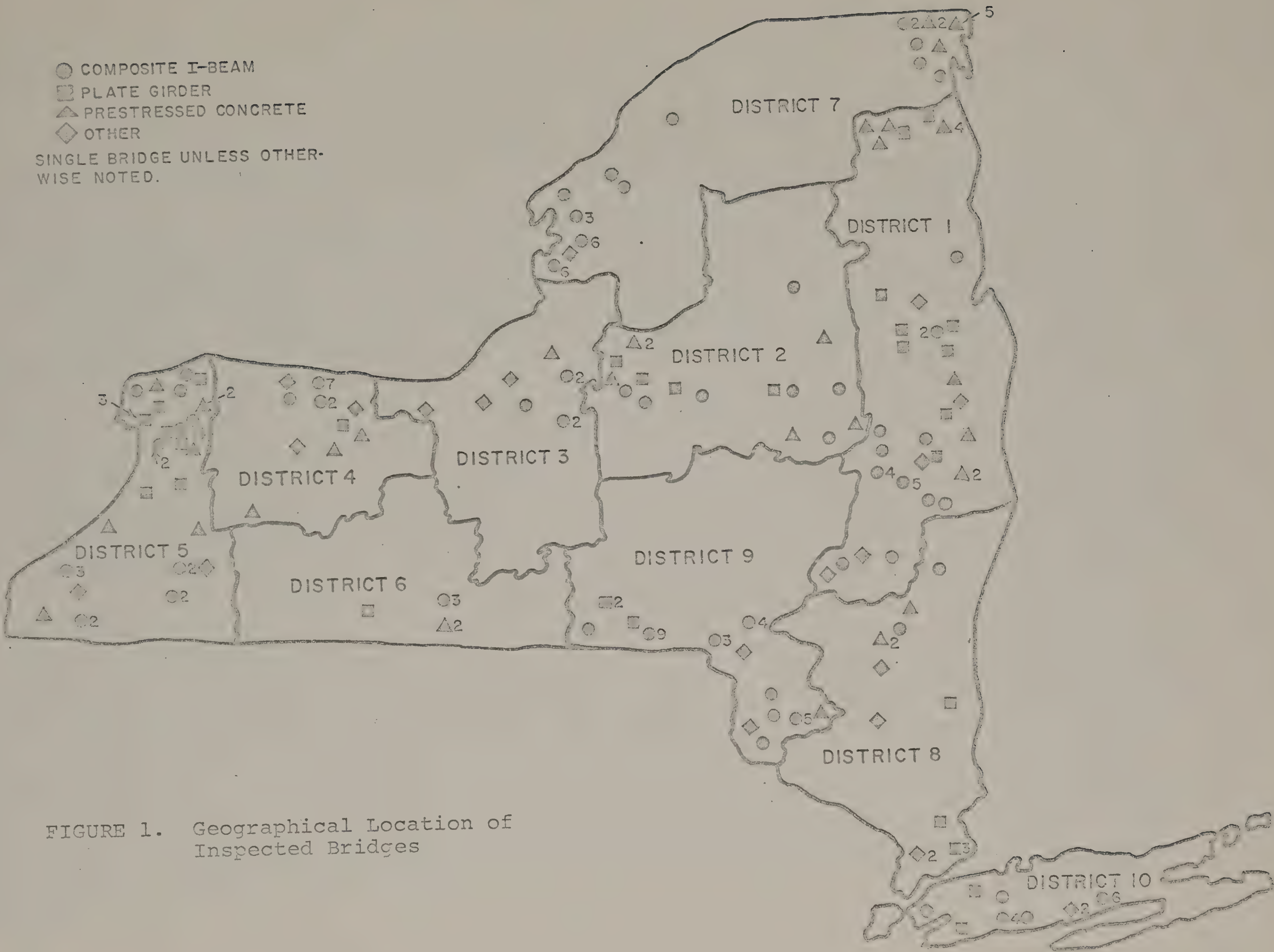


FIGURE 1. Geographical Location of Inspected Bridges

TABLE 1

DESIGN SUMMARY OF INSPECTED BRIDGES

	Composite I-Beam			Composite Plate Girder			Prestressed Concrete Beam		Other*	Totals
Wearing Surface	Simple Span	Cont. Span	Cant. Susp. Span	Simple Span	Cont. Span	Cant. Susp. Span	Simple Span	Cont. Span		
				1963-64 SURVEY						
**P.C.C.	77	3	10	6	3	10	5	-	10	124
***B.C.	105	7	4	15	3	3	47	2	24	210
Total	182	10	14	21	6	13	52	2	34	334
% of Total (334)	54	3	4	6	2	4	16	1	10	100
				1967 SURVEY						
**P.C.C.	64	3	10	4	2	10	5	0	9	107
***B.C.	118	6	4	12	3	3	47	2	23	218
Total	182	9	14	16	5	13	52	2	32	325
% of Total (325)	56	3	4	5	1	4	16	1	10	100

* Includes concrete slab, trusses, arches, rigid frames, aluminum structures, design combinations, (such as composite I-Beam and composite plate girder).

** PCC - Portland cement concrete.

*** BC - Bituminous concrete.

Inspection Procedure and Data Presentation

The surveys consisted of visual inspections conducted by two men; an engineer and a technician from the Bureau of Physical Research assigned to the study. In preparing for the surveys, each man thoroughly reviewed the various types and definitions of distress described in the Highway Research Board Special Report 30 (1957), which was used as a guide. Use of these generally accepted classifications of concrete distress, and the fact that the same project engineer inspected all the structures, minimized the possibility of differences occurring due to personal interpretations.

The severity of distress was defined in qualitative terms rather than quantitatively to simplify the inspection and reduce the time required to survey the large bridge sample. The ratings consisted of the following three qualitative categories, illustrated in Figures 2 and 3:

Light: Incipient deterioration not requiring remedial action; also indicates existence of a minimum number of defects.

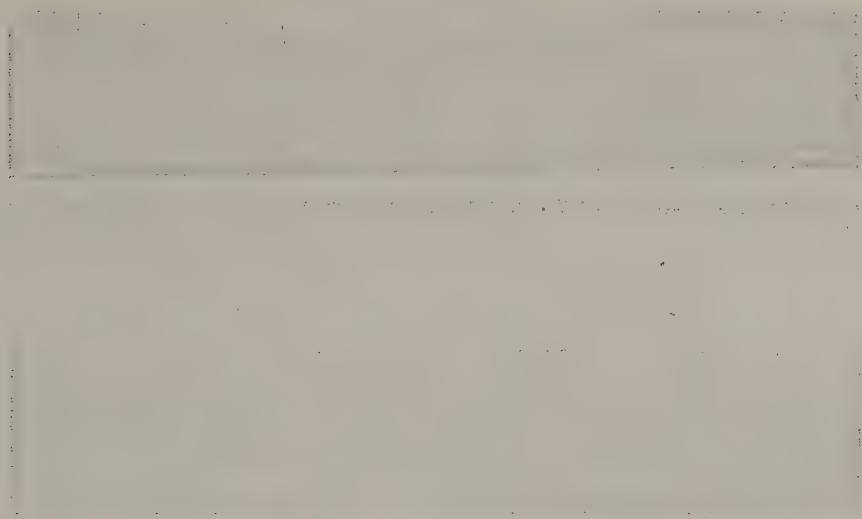
Moderate: A more advanced state of deterioration requiring eventual maintenance; also refers to frequency of occurrence.

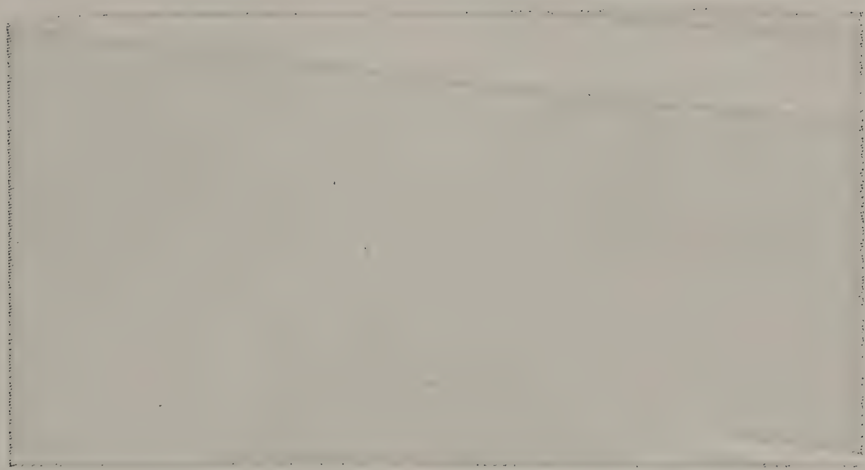
Severe: An advanced state of deterioration requiring remedial action in the near future; also indicates an excessive number of defects.

Results of the two inspection surveys are illustrated in five histograms, depicting the types and extent of distress noted on sample structures, regardless of differences in design, climate, and traffic density. Separate graphic treatment is given the following: 1) wearing surfaces of bituminous concrete, 2) wearing surfaces of portland cement concrete, 3) deck undersides, 4) portland cement concrete with and without air entrainment, and 5) piers.

Distress on Deck Wearing Surfaces

Figure 4 summarizes conditions of wearing surfaces during the 1963-64 and 1967 surveys. In general, the 1967 survey indicated with few exceptions that distress increased with time. The exceptions were apparent improvements in 1) corner cracking on bituminous concrete surfaces, and 2) flecking, scaling, and popouts on the portland cement concrete wearing surfaces. Improved conditions, however, reflect bituminous concrete resurfacing between surveys on portland cement concrete bridge decks with moderate to severe popouts, flecking or scaling. Moreover, some





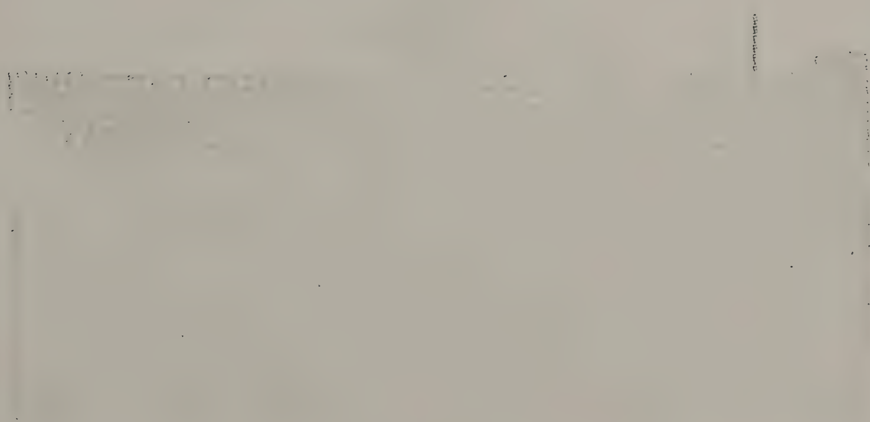


Photo [illegible] of bridge deck condition: "[illegible]" ([illegible]), "medium" (center), and "[illegible]" ([illegible]).

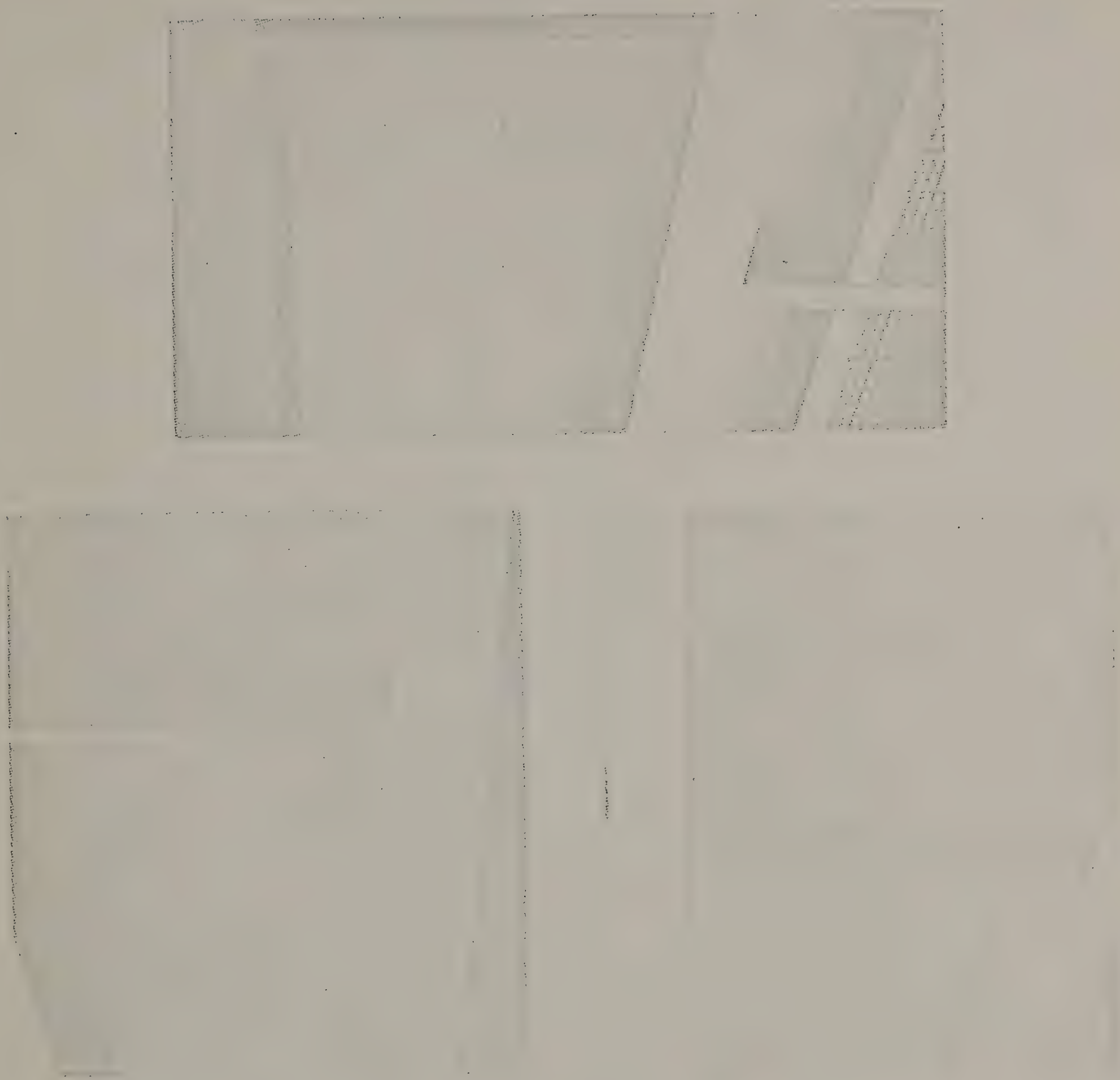


Figure 3. Typical conditions observed beneath deck slabs include: "light" transverse cracking (top), "severe" wet spots and efflorescence (lower left) and "severe" transverse cracking (lower right).

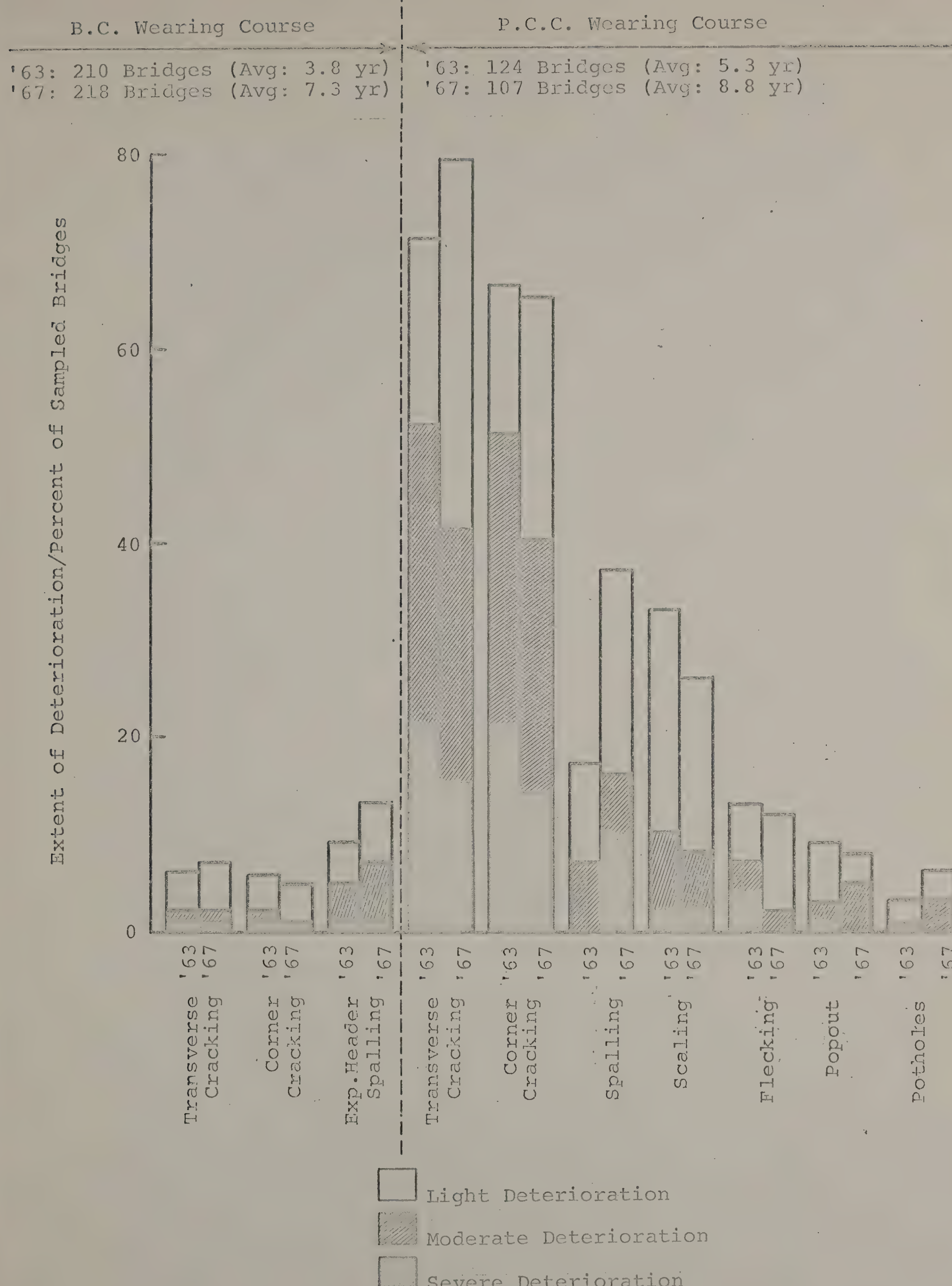


Figure 4. Results of 1963 and 1967 surveys of bridge deck wearing surface condition.

structures with more severe distress were rehabilitated between inspections and consequently were omitted from the 1967 survey. Therefore, the results of each survey were evaluated separately.

Bituminous concrete wearing surfaces had two types of distress: corner and transverse cracking. Both were minor, however, occurring on only 4 and 7 percent, respectively, of the 218 bridge samples surveyed in 1967. Cracking was predominantly reflected from the structural slab below the wearing surface, and thus cannot be charged to the bituminous concrete.

Defects of expansion headers, which are essentially reinforced concrete dams that confine and support the asphalt concrete surface at the bridge expansion joints, are plotted with the bituminous concrete surfaces of which they are segments. The 1967 survey results indicated that 13 percent of the sample had expansion header spalling. Considering that this distress was not directly related to the bituminous concrete and of a minor nature, one can conclude that the bituminous concrete surfaces were relatively free of distress.

Distress was more prevalent on the portland cement concrete surfaces. The 1967 survey of 107-bridges, averaging 8.8 yr of service, indicated that the major types of distress were scaling (26 percent of the structures), spalling (37 percent), corner cracking (65 percent), and transverse cracking (79 percent). Lesser types were flecking (12 percent), popouts (8 percent), and potholes (6 percent). On the basis that the "light" classification of distress implies that repairs are not required, one finds in the "moderate" and "heavy" categories that 41 percent of the structures with transverse cracking, 40 percent with corner cracking, 16 percent with spalling, and 8 percent with scaling require construction maintenance immediately or in the near future. Looking further, the 1963-64 survey indicated 52 percent of the 124-bridge sample had transverse cracking in need of repairs. This fact, together with the relatively young average sample age of 5.3 yrs at the time of the first survey indicated that transverse cracking of concrete bridge deck surfaces was the most significant and prevalent form of distress in the concrete wearing courses examined.

Distress Beneath Deck Slabs

Two forms of distress were noted beneath deck slabs: transverse cracking and leakage. Leakage was identified by moist spots or by signs of efflorescence. Although leakage is not a form of distress, it does indicate that water has permeated the concrete and subsequently can cause deterioration.

The condition of bridge deck undersides is summarized in Figure 5. Bridges with portland cement concrete wearing surfaces had more distress than those with bituminous concrete. This was attributed to two possible factors: age of structures and the use of membrane protective coatings. On the average,

bridges with portland cement concrete wearing surfaces were approximately 1.5 years older. Moreover, 38 bridges or 17 percent of the 218 bridge sample with bituminous concrete had membrane coatings as an interlayer between the deck and wearing course. Further, the apparent superior performance of bridges with membranes is indicated by the fact that 19 of 38 bridges (or 50 percent) had no distress. The remaining structures had light leakage that was not associated with membrane failure.

Air-Entrained vs. Non-Air-Entrained Concrete Decks

A comparison was made between air-entrained and non air-entrained concrete wearing courses inspected in 1967, in terms of types and extent of the more prevalent forms of distress. To reduce disparities between samples, a close balance was attempted by selecting an approximately equal number of structures of each concrete type within the same age grouping. At best, the number and average ages of air-entrained and non air-entrained samples were 40 bridges at 7.5 yrs and 42 at 10.3 yrs respectively.

No significant difference in scaling was noted on wearing surfaces with and without entrained air (26 and 28 percent, respectively), as summarized in Figure 6. These results, which are not in agreement with extensive studies conducted by others, imply that air entrainment is not beneficial in reducing scaling. This apparent contradiction is explained in Part II of this report, where it is shown that the air contents of many cored samples from air-entrained decks were outside the specified limits. Undoubtedly, specified amounts of properly entrained air were not being obtained in the field, particularly at the concrete surface where it is needed most to retard scaling.

In contrast to this performance of non air-entrained concrete wearing surfaces, older decks of this type appear to have developed more widespread scaling. The 1967 survey included 9 other non air-entrained concrete decks between the ages of 12 and 18 years. Five of these were moderately scaled, compared to 3 "light" and 2 "moderate" ratings in the 1963 survey. Several other decks, exhibiting light to severe scaling when inspected in 1963, were resurfaced prior to 1967. While other forms of distress also were noted in these decks, it is reasonable to assume that scaling was a factor in the decision to resurface.

The percent of bridges with corner and transverse cracking was the same for both air-entrained and non air-entrained decks. However, moderate and severe cracking was more prevalent on the non air-entrained decks. A plausible reason for the difference is the fact that the non-air-entrained bridges, on the average, were 2.8 yr older and consequently would be expected to show more extensive distress.

The underside inspection of deck slabs with and without air-entrainment is summarized in Figure 7. Performance was rated in terms of the amount of leakage and/or efflorescence noted. Air-entrained concrete generally gave less evidence of distress than non air-entrained, both in terms of percent of bridges affected and of severity of distress. This suggests that adequate amounts of entrained air were obtained below the immediate

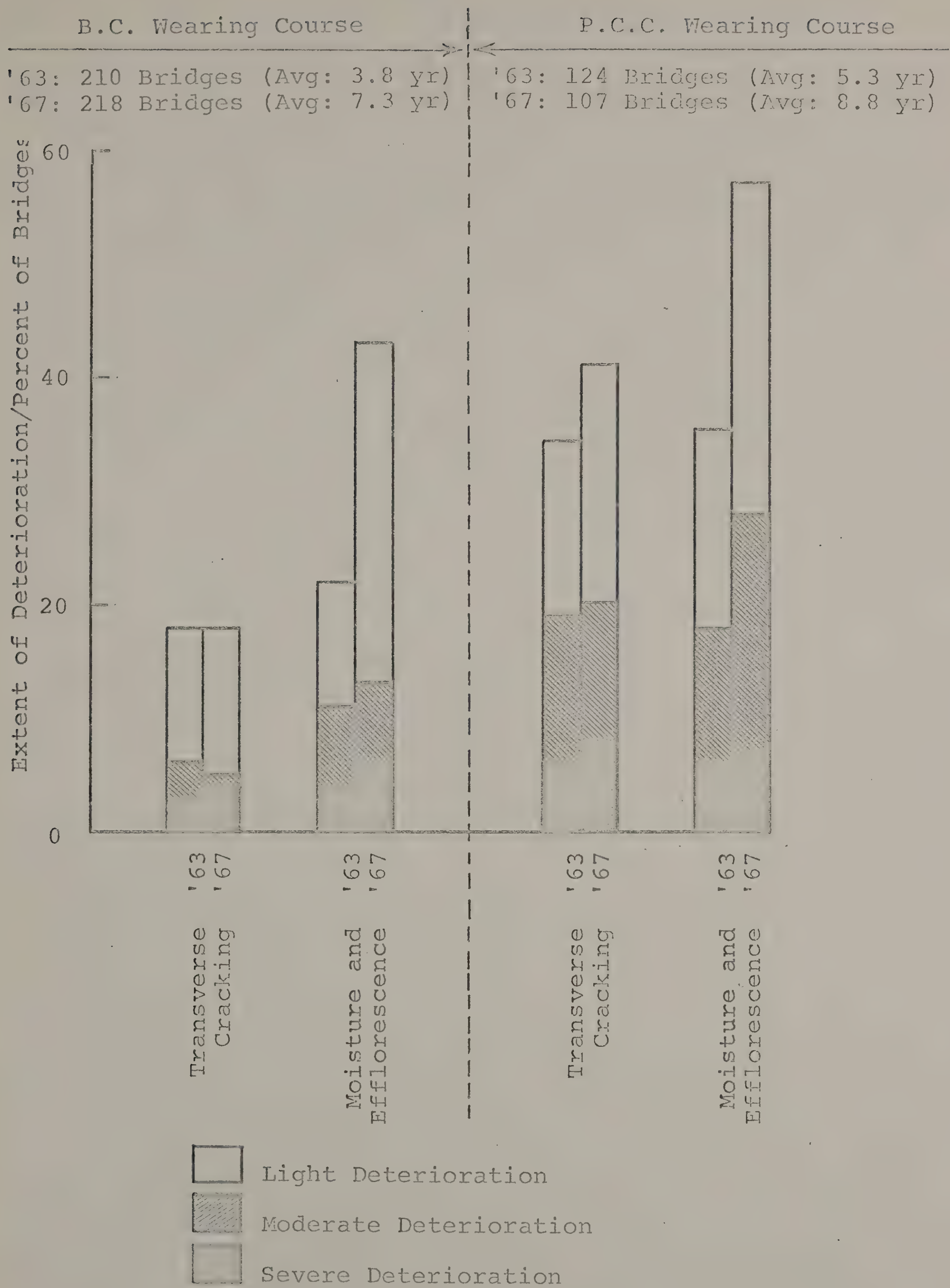


Figure 5. Results of 1963 and 1967 surveys of bridge deck underside condition.

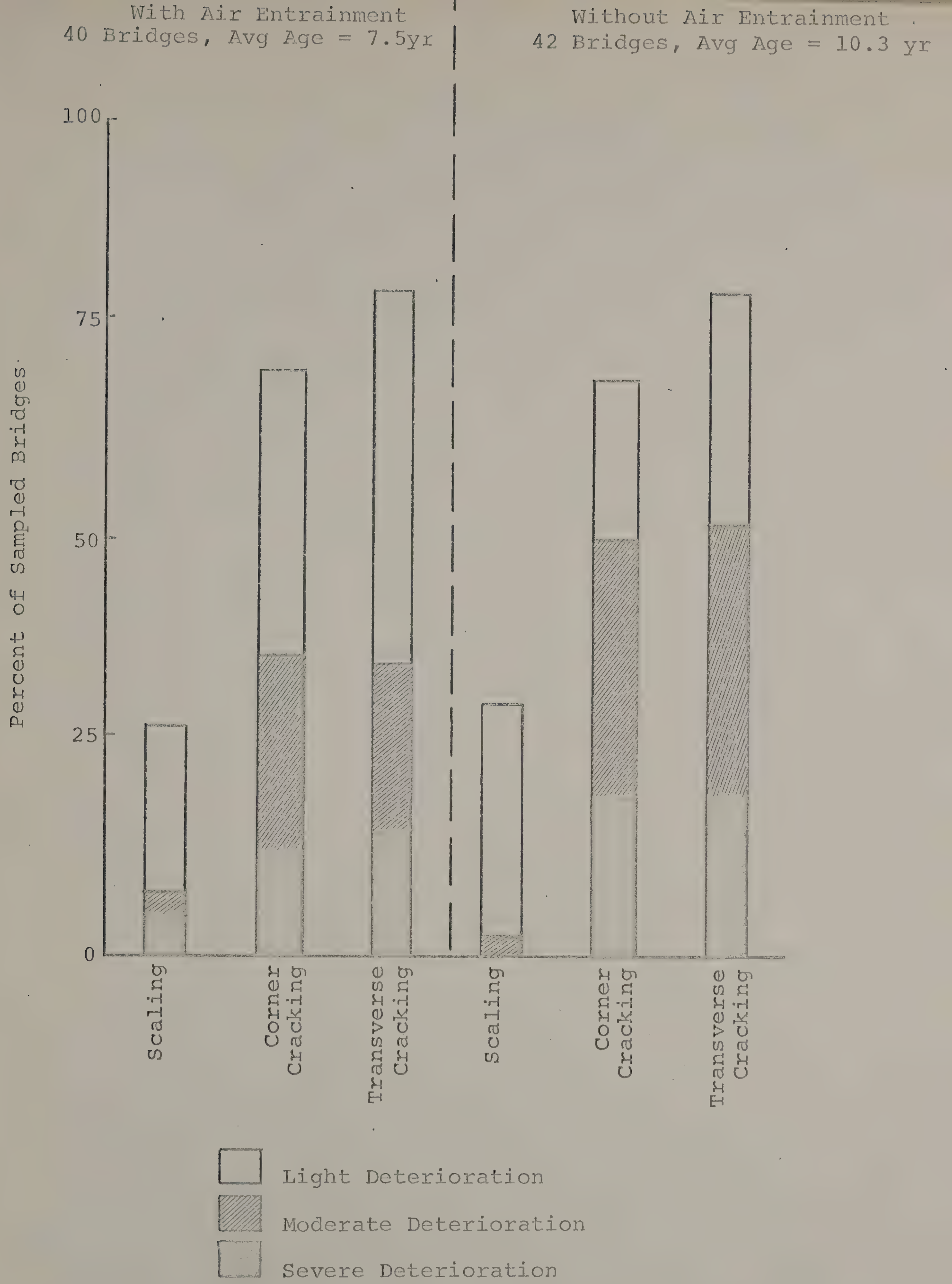


Figure 6. Condition of portland cement concrete deck wearing surfaces, surveyed in 1967.

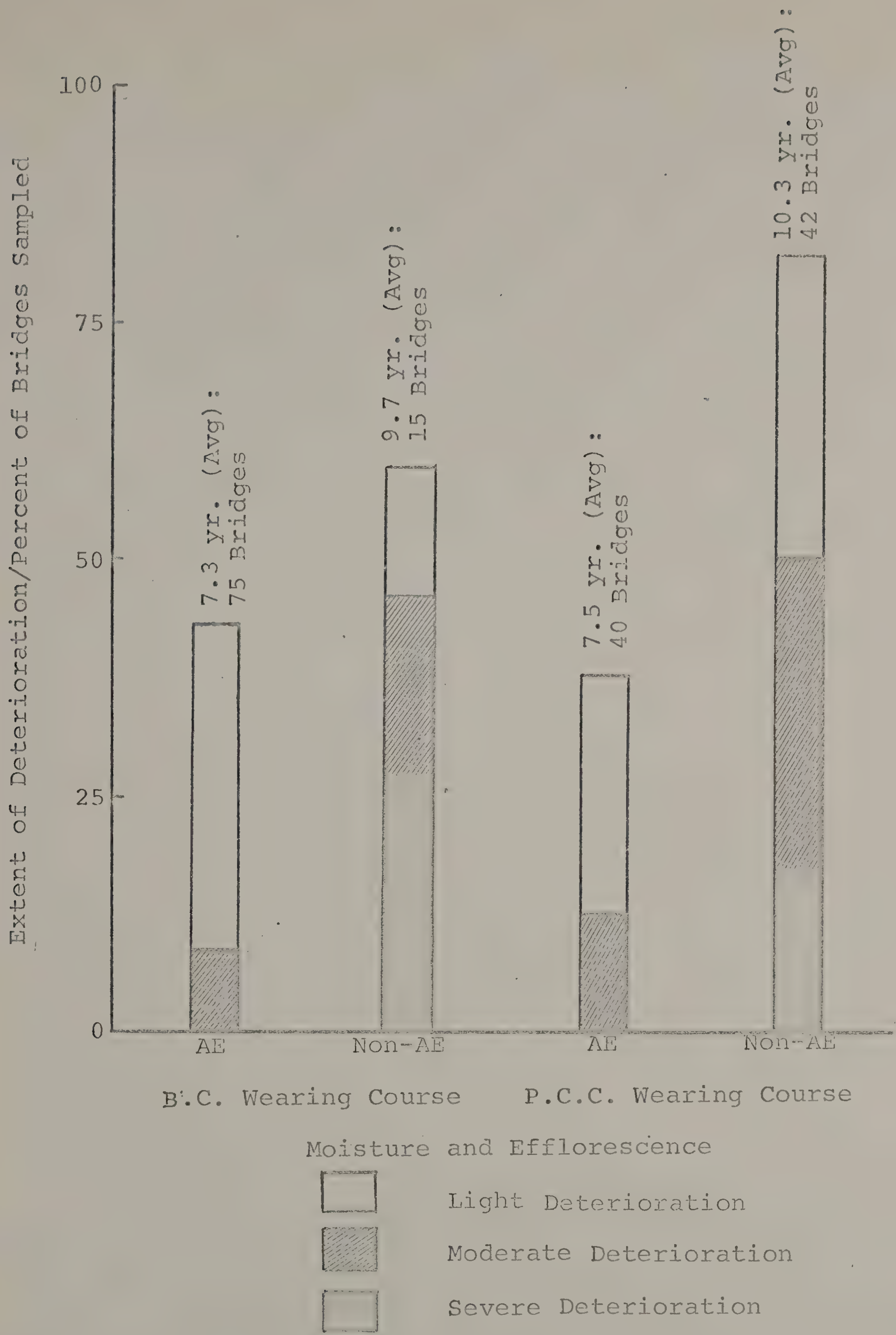


Figure 7. Deck underside condition with and without air entrainment, for bridges of various ages surveyed in 1967.

surface of air-entrained concrete slabs. Satisfactory air-entrainment also is indicated by the fact that air-entrained concrete is less permeable than concrete without properly entrained air. This effect is noted in the Bureau of Reclamation's Concrete Manual (3). On the other hand, the 2.4 yr age difference between the two groups of structures may explain the better performance of the air-entrained slabs.

Deck slab performance was compared with and without air-entrainment with regard to different wearing surfaces. No significant difference was found between air-entrained slabs having either a portland cement concrete or bituminous concrete wearing surface -- 38-percent distress for portland cement and 42-percent for bituminous concrete. When comparing the non-air-entrained structures, however, a greater difference was noted: 60-percent distress for bituminous concrete and 83 percent for portland cement concrete wearing surfaces. Review of the construction records indicated that 2 of the 15 bridges with bituminous wearing surfaces had membrane coatings between the structural slab and the wearing course. This could account for the better performance since neither of these structures showed any evidence of distress.

Distress in Bridge Piers

Although not directly related to bridge deck deterioration, concrete bridge piers were examined during each bridge deck survey. Figure 8 shows the extent and severity of concrete spalling noted on the bridge piers of all structures combined, in addition to only those of simple-span construction. As expected, approximately 85 percent of the distress occurred on bridge piers supporting simple spans, where the open joints over piers permit the destructive forces of moisture and de-icing chemicals to act. Moreover, the second survey revealed that twice as many simple-span bridges had spalled piers in 1967 than in 1963-64. This one hundred percent increase in distress from 17 to 34 percent within a short period of 3 years, indicates a need to correct this increasing problem.

Discussion of Survey Results

In the visual examination of bridge deck surfaces it was noted that those with bituminous concrete (BC) wearing surfaces comprising 2/3 of the bridges surveyed were relatively free of deterioration. Specifically, the major distress noted on these decks was expansion header spalling and this occurred on only 13 percent of the bridges. By contrast, structures with portland cement concrete (PCC) wearing surfaces, though they included only 1/3 of the total bridge sample, showed distress of a more serious nature. Over 60 percent of the decks with (PCC) surfaces had either corner or transverse cracking. More revealing

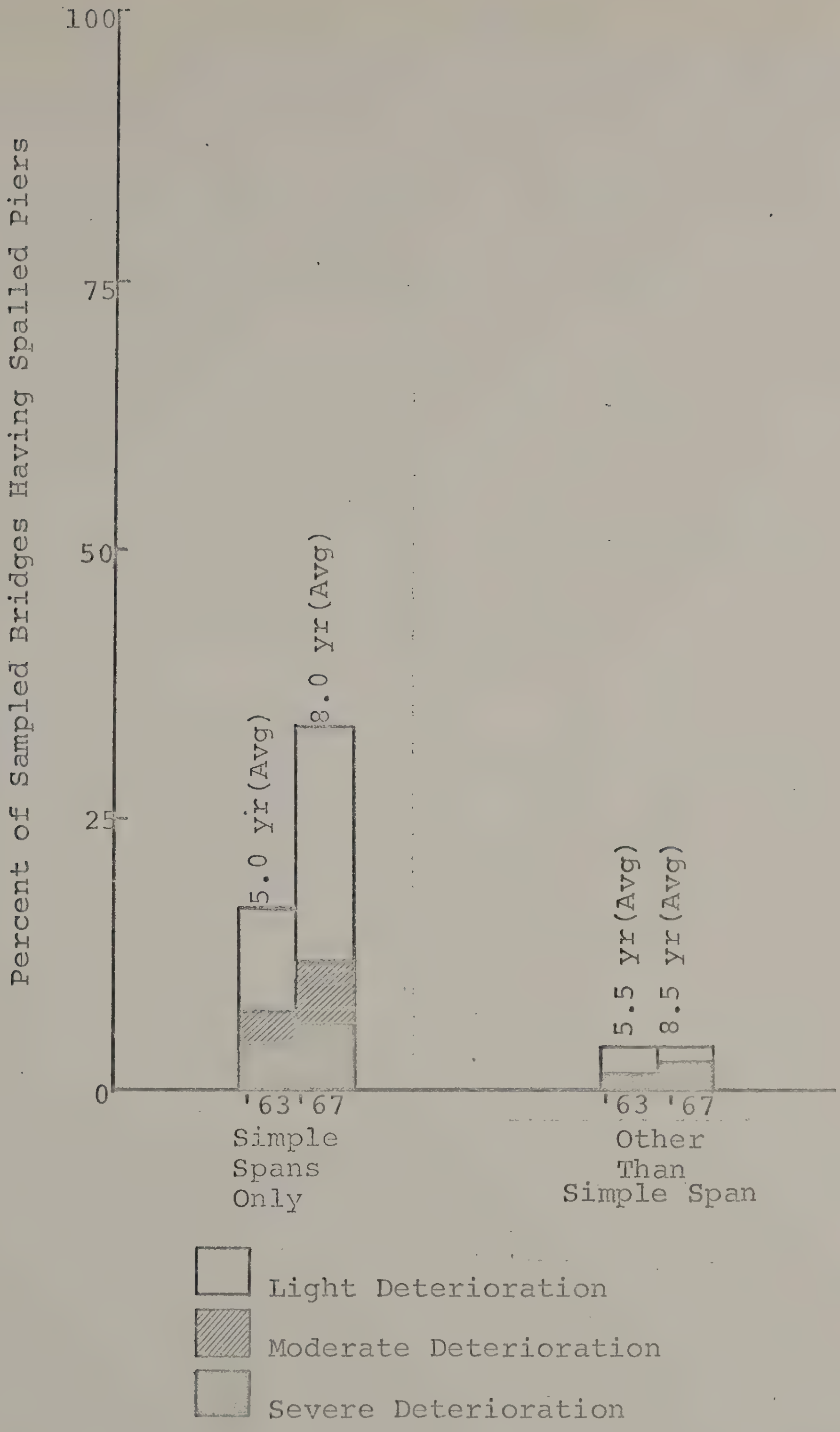


Figure 8. Extent of concrete spalling on bridge piers, encountered in surveys of 1963(n=334 bridges) and 1967(n=325 bridges).

was the fact that 52 percent of these structures had moderate or severe cracking after an average age of 5.3 yrs (based on the 1963-64 survey) and would require repairs in the immediate or near future. This indicates that deck cracking of (PCC) wearing surfaces is a problem area.

The deterioration noted on the underside of the structures was somewhat different than the top. Structures with (BC) wearing surfaces appeared more distressed when viewed from below than they did on the surface. This suggests that (BC) wearing surfaces could camouflage defects that occur in the structural deck. Decks with (PCC) wearing surfaces, on the other hand, appeared less distressed on the underside than on top. The greater deterioration of the concrete deck surface probably reflects its direct exposure to traffic, moisture and de-icing salts, and deficiencies in air content as suggested below.

In comparing the performance of all decks having (PCC) concrete wearing surfaces with those with (BC) wearing surfaces based on inspection of the underside, it appears that distress was more severe on the structures with (PCC). The average age difference of only 1.5 yr between samples is not an important consideration. More significant is the fact that 38 bridges of the (BC) sample had concrete protective coatings and fifty percent of these structures showed no evidence of distress. Unquestionably, coatings used as membranes provide protection.

A comparison was made between (PCC) wearing surfaces with entrained air and those without specified air contents. Inspection of the surface indicated no significant difference in appearance between decks with or without specified air contents. These results are not in agreement with laboratory and field tests which have demonstrated that properly entrained air offers added resistance, particularly to scaling. A review of the same structures from the bottom side of the deck indicated that the air entrained decks had less distress in the form of moisture and efflorescence than those without air. Considering that scaling occurred on approximately 25 percent of the air-entrained concrete wearing surfaces, it can be inferred that specified air contents were not always obtained at the concrete surface. Causes frequently ascribed to this problem include use of "wet" mixes and overfinishing.

The inspection results of bridge piers showed that concrete spalling was a major problem only on simple-span structures. This is quite obvious, inasmuch as the simple-span joints are over the pier supports. A logical solution is to eliminate the joint over the piers by using continuous or cantilevered suspended spans. If simple-span construction is a requirement, however, proper protection must be provided by preventing surface water from making contact with the concrete piers. To date, none of the concrete protective coatings have proven satisfactory. Presumably, the control of water flow by conduit or other means must be provided.

Conclusions

Based on the condition survey of 334 bridges which represent a cross-section of structures constructed in New York State between 1950 and 1961, it is concluded that:

1) Transverse and corner cracking are the most prevalent types of distress noted on the surface of portland cement concrete wearing courses, both air-entrained and non-air-entrained. This is borne out by the fact that after an average service life of 5.3 yr, over 50 percent of these decks had moderate or severe cracking in need of immediate or future repairs.

2) Bituminous concrete wearing surfaces were essentially free of distress, even though the underside of their structural decks exhibited cracking and evidence of leakage. This raises the possibility that (BC) wearing surfaces could conceal distress that may occur in the upper portion of structural decks.

3) Air-entrained concrete wearing courses in service an average of 7.5 yr exhibited the same degree of scaling as 10-yr old (average) decks consisting of non air-entrained concrete. Approximately 25 percent of both types developed light to moderate scaling. This is probably due to insufficient air content at the surface.

4) Scaling of non air-entrained concrete wearing surfaces is progressing with age, as evidenced by a higher incidence of distress in older decks.

5) Spalling of concrete bridge pier cap beams and columns, both with and without air-entrainment, occurred mainly on simple-span bridges because of leakage through the joints, and is continuing.

PART II: STUDIES OF BRIDGE DECK DETERIORATION

Based on the results of the Part I survey of 334 bridges, 54 structures were selected for further study to determine possible causes for the types of distress noted. The studies attempt to correlate distress with various field and laboratory measurements of:

1) Vibrations induced by normal traffic loading

2) Surface roughness

3) Chloride content of concrete cores

4) Air content of concrete cores

5) Depth and condition of steel reinforcing mesh in concrete slabs

Table II lists the selected bridges and tests conducted on each structure.

Vibration Measurements

Because transverse cracking of Portland Cement concrete wearing surfaces was the most prevalent defect noted during the condition survey, an attempt was made to correlate cracking with dynamic behavior. Accordingly, 18 bridges with varying degrees of cracking were field tested under normal traffic loading.

Test Equipment - Vibration measurements were made with Statham (strain gage type) accelerometers wired to a dual channel, oscillograph recorder which produced continuous traces on a strip chart. Vehicle average speed and relative position on the bridge were determined from event marks recorded on the chart by a stylus activated by air-impulse traffic hoses positioned at measured distances on the bridge. Power to operate the system was furnished by a 12 Volt D.C. car battery through a Terada transistorized D.C. to A.C. power converter. The test instruments are shown in Figures 9, 10, and 11.

Test Procedure - Initially traffic signs and cones were placed on the bridges to control traffic and permit the installation of test instruments. Accelerometer pickups were then located at various span positions within the blocked off areas and bonded to the deck slab with Duxseal, a putty-like substance (Fig. 10). A minimum of three traffic hoses, fastened to the concrete deck with metal clips and Ramset Fasteners, were connected to air impulse converters, which were wired to oscillograph recorders. A power cable was conducted from the recorders to a vehicle located off the bridge. Figure 12 depicts an overall view of the test setup, excluding the recorders and vehicle.

TABLE II

BRIDGES SELECTED FOR FIELD AND LABORATORY STUDIES

FILE NO.	DESIGN	SUPPORT	WEARING SURFACE	ACCEPT. DATE	ROADWAY WIDTH ft.	TOTAL LENGTH ft.	TESTS & STUDIES: VIBRATIONS	SURFACE ROUGH	WIRE MESH	CHLORIDE TEST	AIR CONTENT	REMARKS
1-2	Plate Girder Composite	Cant. Susp. 5-Span	Concrete	6/60	30'	1135'	*	*				Transverse cracks developed when structure was opened to traffic Epoxy resin used to seal several cracks appears to be working satisfactorily. Moderate to severe transverse and corner cracking. Light scaling and spalling.
1-6	CIB	Simple 4-Span	Asphalt	1/63	26' ea.	211'7"		*		*	*	New bridge very near bridge no. 1-7, subjected to about same volume of traffic. Light transverse cracking on wearing surface and structural slab.
1-7	CIB	Simple 4-Span	Concrete	10/60	39' ea.	231'	*	*		*	*	Severe Scaling on three panels: Moderate traffic.
1-8	CIB	Simple 3-Span	Asphalt	12/59	54'	158'6"		*			*	Portions of slab show rust stains, otherwise structure is in good condition.
1-13	AIB	Simple 4-Span	Concrete	7/55	26'	203'			*	*	*	No salt used on this wearing surface: Lightly traveled - very good condition.
1-18	Plate Girder	Continuous 2-Span	Concrete	12/55	36'	240'	*	*	*	*	*	Slab is severly cracked - much more than the wearing surface: High skew(69°).
1-23	Conc. Slab	1-Simple Span	Asphalt	5/57	22'	68'6"				*	*	Slab concrete is 17" thick. Deck is in excellent condition.
1-35	Arch Susp.	7 simple spans 1 Suspended Span	Concrete	12/59	42'	773'	*	*	*	*	*	Transverse cracking on wearing surface.
1-36	CIB	Simple 3-Span	Concrete	1/50	44'	205'	*	*	*	*	*	Slab is in good condition. Light cracking on wearing surface.
1-3	CIB	Simple 4-Span	Concrete	/59	30'	348'	*	*				Short, fine cracks on wearing surface.
1-3	CIB	Cant. Susp.	Concrete	/59	30'	532'	*					Short, fine cracks on wearing surface.
2-1	CIB	Simple 3-Span	Concrete	10/57	29' 41'	149'6"	*		*	*	*	Severe cracking on slab: Slab is very moist: Severe efflorescence.
2-15	Plate Girder	1-Span Cant. Susp. 2 Anchor 1-Simple	Concrete	8/57	24'	593'			*	*	*	Severely cracked top & bottom.
2-27	CWFB	Simple 3-Span	Asphalt	8/61	26'	171'6"				*	*	

TABLE II

BRIDGES SELECTED FOR FIELD AND LABORATORY STUDIES

FILE NO.	DESIGN	SUPPORT	WEARING SURFACE	ACCEPT DATE	ROADWAY WIDTH ft.	TOTAL LENGTH ft.	TESTS & STUDIES: VIBRATIONS	SURFACE ROUGH	WIRE MESH	CHLORIDE TEST	AIR CONTENT	REMARKS
2-20	PCB	Simple 1-Span	Concrete	8/59	38'	60'						Prestressed box beam with concrete wearing surface: has extra steel in wearing surface. Skew of 26° 30', no evidence of corner cracking. Small, fine incipient cracking on surface.
3-4	CIB	Simple 4-Span	Concrete	9/58	50'	266'6"			*	*	*	Some scaling evident on wearing surface.
3-7	CIB	Simple Continuous	Asphalt	11/59	64'	316'8"				*		Slab very good
3-8	AIB	Simple	Concrete	3/54	36'	373'			*	*	*	Portions of the piers are deteriorating: Some slab concrete is poor. Wearing surface has medium transverse and corner cracking.
4-1	AIB	Simple 4-Span	Concrete	12/55	36'	176'			*	*	*	Very good condition underneath. Light scaling, spalling, and cracking on surface.
4-3	Plate Girder	Cant. Susp.	Concrete	12/55	35'	383'5"						One section of deck slab is badly broken up.
4-19	CIB	Continuous 3-Span	Asphalt	12/61	40'	167'6"				*	*	Slab shows moderate cracking & efflorescences. Epoxy seal coat between slab & Wearing surface.
4-25	CIB	Simple 4-Span	Res.	1/59	30'	201'				*	*	Recently resurfaced and in good condition.
4-35	AIB	Simple Cant. Susp. 15-Spans	Resurfaced	2/56	36'	1177'			*	*	*	Slab shows moist areas & cracking: this bridge has much maintenance performed on it.
4-36	Concrete "T" Beam	Continuous 4-Span	Concrete	11/64	35' 60'	190'	*					Concrete Test Bridge Reinforced with High-strength Steel. Condition is excellent.
5-3	Plate Girder	Simple 7-Span	Asphalt	1/64	60' 48'	210'				*	*	Heavily trafficked bridge. Expansion headers heavily spalled S.I.P. metal forms underneath.
5-5	AIB	Simple 3-Span	Concrete	7/56	26'	174'			*	*	*	Severe scaling on wearing surface. Also seems to vibrate considerably.
5-10	AIB	Simple 1-Span	Res.	6/57	32'	66'				*	*	Few moist spots underneath, otherwise slab is in good condition.
5-13	AIB	Cant. Susp. and Simple 7-Spans	Concrete	7/57	30'	650'			*	*	*	Wearing surface severely cracked. Light scaling on surface and wire mesh exposed. Light efflorescence and cracking underneath.
5-16	AIB	Simple 2-Span	Concrete	12/55	36'	111'6"				*	*	Severe cracking on wearing surface. Moist spots on underside.
5-17	AIB	Simple 3-Span	Concrete	12/55	36'	125'8"			*	*	*	Medium transverse and corner cracking on surface. Underside in good condition.
5-28	CWFB	Continuous 3-Span	Concrete	1964	24'	260'				*	*	Many full lane transverse cracks on wearing surface. Slab looks good underneath.

TABLE II

BRIDGES SELECTED FOR FIELD AND LABORATORY STUDIES

FILE NO.	DESIGN	SUPPORT	WEARING SURFACE	ACCEPT DATE	ROADWAY WIDTH ft.	TOTAL LENGTH ft.	TESTS & STUDIES: VIBRATIONS	SURFACE ROUGH	WIRE MESH	CHLORIDE TEST	AIR CONTENT	REMARKS
5-34	AIB	Continuous 2-Span	Asphalt	1/53	20'	164'				*	*	Slab and wearing surface are in good condition.
6-1	Composite Deck Girder	Simple 10-Span	Concrete	6/59	26' ea.	1377'	*			*	*	Moderate cracking on both wearing surface & slab.
6-2	AIB	Simple 4-Span	Concrete	9/56	19'	215'3"	*			*	*	Excessive cracking on slab-more so than on wearing surface: the cracks are generally short (1'-3') similar to those observed on wearing surface of cantilever - suspended bridges.
6-3	AIB	Cant. Susp. 3-Span	Concrete	9/56	49'	206'	*			*	*	Very short cantilevered section: Excessive transverse cracking on both wearing surface and slab.
7-31	CIB	Simple 3-Span	Asphalt	12/59	30'	256'				*		Relatively high bridge (piers over 40 ft. high). S.I.P. metal forms underneath.
7-35	CIB	Simple 5-Span	Asphalt	10/59	26'	355'7'				*	*	Lightly trafficked bridge. S.I.P. metal forms underneath.
8-1	PCB	Simple 4-Span	Asphalt	7/60	30'	183'6"	*					Signs of considerable leakage between beams.
8-2	CIB	Cant. Susp. 3-Span, 2 Anchor, 1 Suspended	Concrete	7/60	30' ea.	350'	*	*		*	*	Medium transverse and corner cracking on surface. Efflorescence noted underneath.
8-5	PCB	Simple 3-Span	Concrete	11/59	30'	156'	*	*			*	Random cracks on wearing surface: Evidence of leakage between beams on 5% grade.
8-6	AIB	Simple 6-Span	Concrete	7/54	36'	299'	*			*	*	Wearing surface severely cracked: No cracking evident on slab bottom. Underside in good condition.
9-4	CIB	Simple 3-Span	Concrete	7/60	30'	156'				*	*	Wearing surface is in very poor condition however the slab bottom is very good: Several potholes in wearing surface.
9-10	CIB	Simple 3-Span	Concrete	10/60	30'	139'5"				*	*	Similar to bridge no. 9-4: On same rt Wearing surface is poor, slab bottom is good.

TABLE II

BRIDGES SELECTED FOR FIELD AND LABORATORY STUDIES

FILE NO.	DESIGN	SUPPORT	WEARING SURFACE	ACCEPT. DATE	ROADWAY WIDTH ft.	TOTAL LENGTH ft.	TEST & STUDIES: VIBRATIONS	SURFACE ROUGH	WIRE MESH	CHLORIDE TEST	AIR CONTENT	REMARKS
9-12	Deck Girder	Cant. Susp. 3-Span	Res.	6/54	34'	500'				*	*	Although resurfaced, slab appears good.
9-17	CIB	Simple 4-Span	Concrete	1/61	36'	288'				*	*	Many cracks, some shrinkage on wearing surface: Slab Looks good.
9-21	AIB	Simple 1-Span	Concrete	1/57	49'	47'				*	*	Excessive shrinkage cracks: Slab had several moist areas but very few cracks.
9-24	CIB	Simple 4-Span	Concrete	10/59	36'	285'				*	*	Cracking on wearing surface. Slab is severely cracked.
9-27	AIB	Simple 1-Span	Res.	2/52	34'	60'				*	*	Although several moist spots are evident on slab, there are no noticeable cracks.
9-31	CIB	Simple 9-Span	Concrete	12/63			*			*		Full-depth cracks had developed in wearing surface before it was accepted: Is on a horiz. curve & is highly superelevated.
9-32	CIB	Cant. Susp.	Concrete	12/63	30' ea.	519'	*					Short transverse cracks extending from longitudinal joint started before acceptance.
10-2	Plate Girder	Cant. Susp. 15-Span	Concrete	6/49	25' ea.	2142'				*	*	Wearing surface beginning to break up: Slab has several moist areas and some short cracks, however, it is in good condition.
10-11	CIB	Simple 4-Span	Concrete	3/60	36' ea.	237'				*	*	Wearing surface is cracked: Slab is very good.
10-25	Plate Girder & I-Beam	Continuous 16-Span	Concrete	9/56	38' ea.					*	*	Very heavy truck traffic - high speed: Wearing surfaced broken up: No shear connectors. Slab shows light to moderate cracking.
10-26	Girder Composite	Continuous & Simple 11-Spans	Concrete	6/60	39' ea.	1567'				*	*	Many cracks have formed 10' to 15' apart which appear to extend through slab: Cracks on continuous section over R.R. are spaced approximately 5' appart.

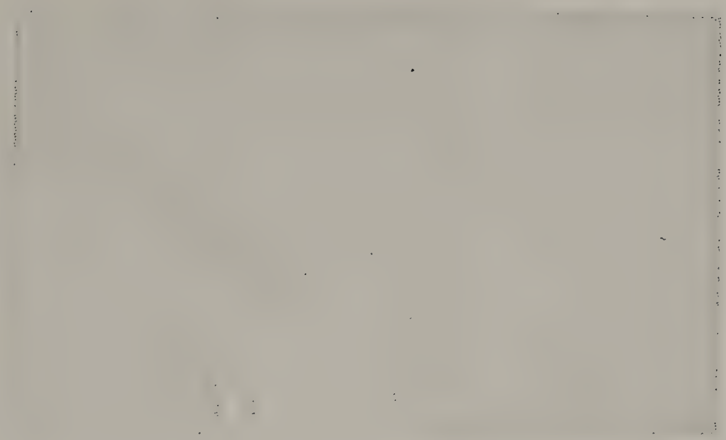


Figure 9. A Statham (strain gage type) accelerometer.

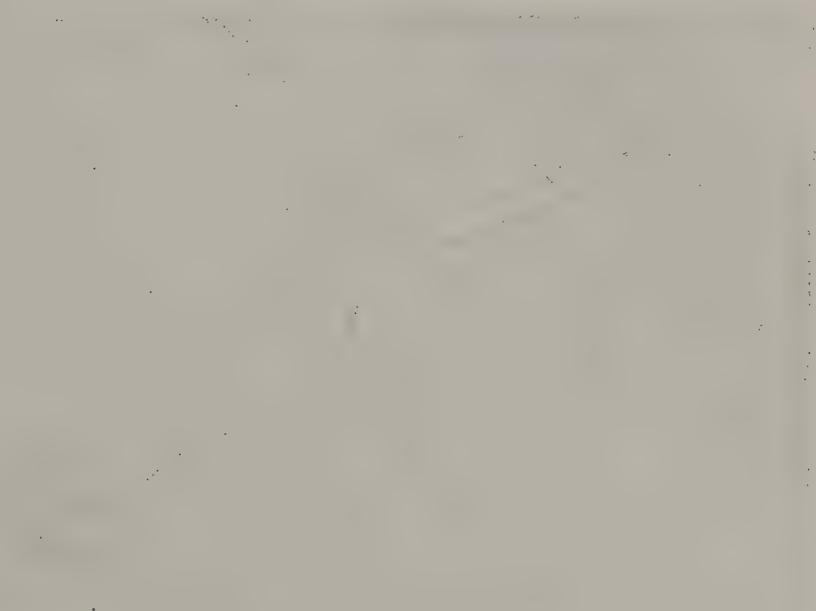


Figure 10. [illegible] oscillograph dual channel strip chart recorder and two accelerometer pickups attached to pavement with Duxseal.

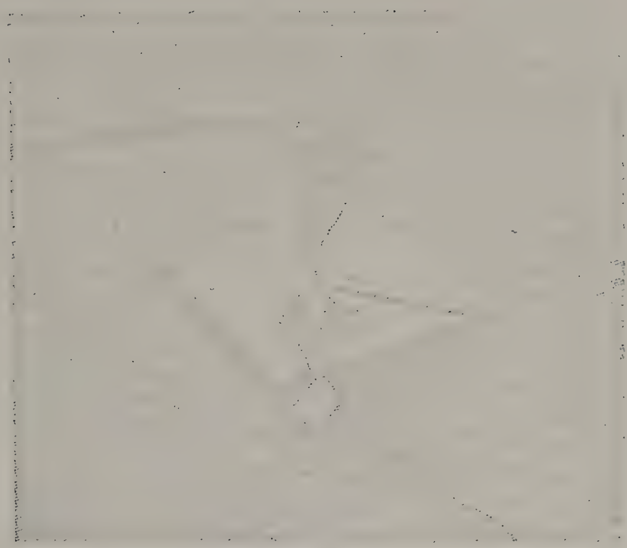


Figure 11. Diaphragm converting air impulse into electrical signal for recorder event marker.

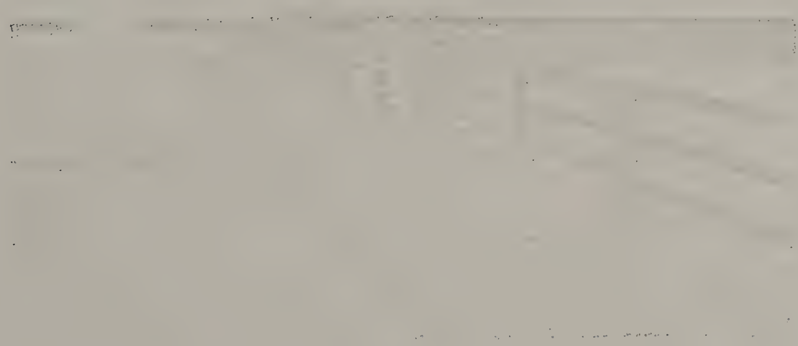


Figure 12. Overall view of vibration test setup, showing traffic cones; traffic hoses, and accelerometer pickups.

Three men were required to conduct the tests. One man operated the oscillograph recorder, while another tabulated vehicle data, such as: number and types of vehicles on the span and number of vehicle axles. A third man assisted with traffic control and corrected any operational problems which arose. Prior to testing, the same personnel conducted a thorough visual inspection of the top and underside of each deck, noting and sketching distressed areas.

Vibration Test Data - Bridge vibration parameters namely, natural frequency, damping and dynamic displacement, were determined from the oscillograph traces of acceleration. This was possible, even though acceleration lags actual movement by a phase angle of 180 degrees, because they produce identical wave forms.

Fundamental Frequencies - Fundamental frequencies were determined from measurements of trace record segments corresponding to the freely oscillating condition after vehicles left the span. A minimum of 5 free oscillating cycles containing a sinusoidal wave pattern were used to determine natural frequency. Usually, traffic on adjacent spans or twin structures supported by a common pier affected free movement of the tested structure to the extent that the wave form was not a pure sine wave. Consequently, many test runs were required before suitable traces could be used for frequency measurements. Only 38 percent of 1421 total traces could be used for frequency measurements, and even these showed variations of as much as 2 cps. or approximately 20 percent.

Natural frequencies were also determined theoretically, but only for simple span structures because of complexities in determining frequency equations for the continuous and cantilevered suspended span structures. The theoretical frequency equation for the simple span bridges is as follows:

$$f = \frac{\Pi}{2L^2} \sqrt{\frac{EIg}{W}}$$

Where:

f = theoretical frequency (cps.)

L = span length, center to center of bearings (inches)

E = modulus of elasticity of steel (psi)

I = moment of inertia of transformed section at midspan, exclusive of windbracing, cross framing, sidewalks, curbs and railings ($in.^4$)

g = acceleration due to gravity (in./sec.^{2})

W = unit weight of bridge cross section at midspan (lb./in.)

Assumptions made in applying the above equation include 100 percent composite action, a fully cracked section, and a modular ratio of n=8 for the transformed section of concrete.

Damping Factors - Damping factors were determined from the same trace record segment used for the fundamental frequency measurements. The equation was as follows:

$$S = \frac{\ln A_o - \ln A_n}{2\pi n} \quad (6)$$

Where:

S = damping factor

$\ln A_o$ = natural log of amplitude of 1st cycle of curve

$\ln A_n$ = natural log of amplitude of nth cycle of curve

n = minimum of 5 consecutive cycles of curve

Dynamic Displacements - Vertical displacements of each structure were calculated from maximum peak to peak acceleration values measured from each trace. The computed values are relative displacements rather than total live load displacements, the latter consisting of static live load displacement plus one-half the computed values. Since relative displacements do not reflect total stresses, they were used only to compare movements with pavement cracking patterns.

Dynamic displacements were calculated from the equation:

$$d = \frac{a_{max}}{4\pi^2 f^2}$$

Where:

d = maximum peak to peak displacement (inches)

a_{max} = maximum peak to peak acceleration (in./sec.^{2})

f = measured frequency (cps.)

The above equation assumes that the structures are oscillating in simple harmonic motion. Actually, dynamic effects of the vehicle-structure system produced traces of irregular patterns which were averaged as sine waves of simple harmonic motion for computation purposes.

Typical vibration traces shown in Figure 13 represent a 3-axle dump truck travelling over a 61-foot, simple span, composite I-beam structure at an average velocity of 26.5 miles per hour. The top trace is a record of vibrations induced at midspan while the bottom trace represents movement at the quarter-span. Greater amplification of the signal at quarter-span, which was necessary to produce a satisfactory trace for measurement, gives the impression that bridge movements at the quarter point are greater than those at midspan. Actually, the maximum peak to peak displacement of 0.031 inches occurred at midspan. The bridge deck fundamental frequency and damping coefficient for this test run were 4.7 cps and 0.022, respectively.

Test Results - Table III shows bridge deck vibration data for the 18 bridges studied. Minimum and maximum values of measured frequencies, dynamic displacements and damping coefficients varied from 2.4 to 16.6 cps, 0.002 to 0.154 double amplitude in inches, and 0.003 to 0.088, respectively. The ratio of measured to theoretical frequencies in simple span structures covered a range of 0.91 to 1.92, with an average value of 1.28. Since natural frequencies are directly proportional to the stiffness of a material, the test results showed that the bridges were actually stiffer than the computations indicated. Differences between actual and theoretical frequencies are mainly attributed to the added stiffness offered by the windbracing, crossframing, and sidewalks which were not considered in the theoretical frequency calculations, and other assumptions necessary to compute the moment of inertia of the bridge.

Vibrations Vs. Cracking - Several approaches were used to analyze vibrations and their relationship to bridge deck cracking. The first was a statistical analysis to determine if degree of cracking correlated with bridge displacements, natural frequencies and damping factors. No correlation was evident. This may be attributable to the fact that the load histories of the structures, which undoubtedly influence cracking of the concrete wearing course, were not available. Some components of load histories which could affect cracking are vehicle weights, patterns of vehicle spacing and speed, and the number of vehicles on the structure simultaneously.

The second approach was a visual examination of vibration traces of bridges exhibiting severe cracking to determine if a correlation existed between cracking and resonance of bridge decks under live load. Hayes and Sbarounis (4) suggest that undersirable bridge vibrations can be produced if the frequency of application of vehicle axle loads coincide with the natural vibrating frequency of a bridge. In this regard, vehicle average speeds and axle spacings determined from oscillograph records were compared with respective bridge deck natural frequencies to note if resonance occurred. Resonance was found to be possible in some instances, but this did not correlate with cracking of the decks.

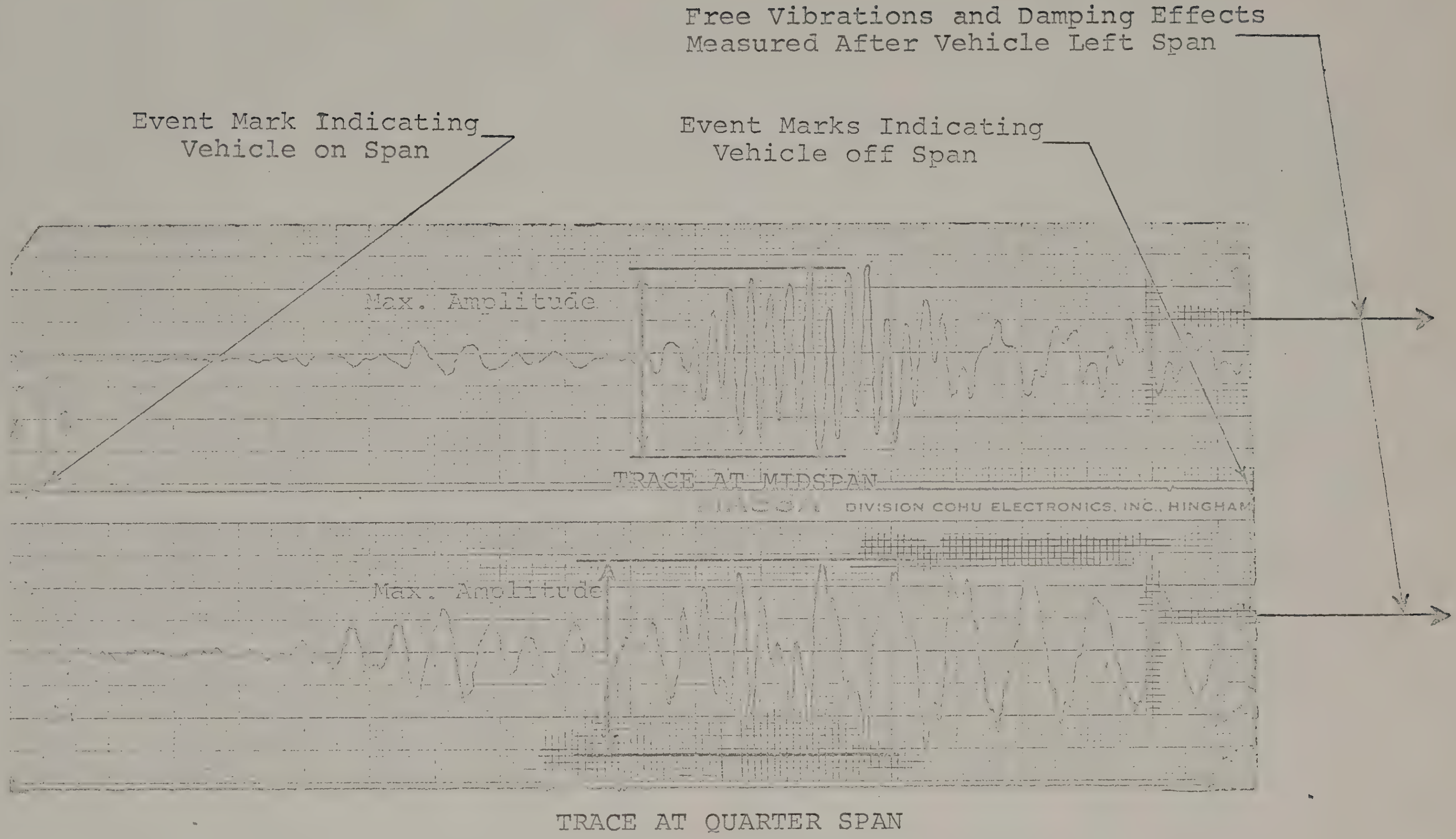


Figure 13 - Typical Vibration Traces

TABLE III

BRIDGE DECK VIBRATION DATA

Bridge File Number	Year Built	Design Spans	Design Type	Shear Conn.	Span Number	Span Length (Ft.)	Span Width (Ft.)	Relative Displacement Double Amplitude Inches	Damping Coeff.	Measured Frequency (CPS)	Theor. Frequency (CPS)	Ratio Measured/Theor.
1-3	1959	4 Simple	Comp. beam	Spiral	E-1	87'	30'	.055	.088	3.96	2.94	1.35
					E-2	87'	30'	.077	.088	3.96	2.94	1.35
1-7	1959	4 Simple	Comp. beam	Stud	N-1	60'	39'	.011	.025	6.57	5.63	1.17
					N-2	60'	39'	.019	.012	6.59	5.63	1.17
					N-3	54'	39'	.005	.032	8.00	6.60	1.21
1-35	1959	3 Simple	CIB	Stud	S-2	35'	42'	.017	.004	16.62*	16.75*	0.99
1-36	1949	3 Simple	Comp. beam	Spiral	S-1	61'	44'	(.007)	(.007)	(5.96)	4.74	1.26
					S-2	61'	44'	.031	.017	4.80	3.95	1.22
					N-1	71'	44'	.023	.015	4.80	4.09	1.18
2-1	1957	3 Simple	Comp. beam	Spiral	N-1	48'	74'	(.002)	(.034)	(10.86)	7.98	1.36
					N-2	56'	74'	.009	.015	7.81	6.97	1.11
5-1	1958	10 Simple	Comp. Deck Girder	Spiral	E-1	163.4'	26'	(.073)	(.003)	(3.63)	2.09	1.74
					N-1	141.0'	26'	.059	.008	3.67*	2.55	1.44
					N-9	93.2'	26'	.085	.012	4.44	4.04	1.10
					N-10	114.1'	26'	.099	.007	3.62*	3.15	1.14
6-2	1955	4 Simple	Comp. Beam	Spiral	W-1	38'	42'	(.008)	(.008)	(10.00)	10.94	0.91
					W-2	59.5	42'	.017	.018	7.09*	5.67	1.25
8-1	1959	4 Simple	PCB	-	N-1	37.5'	30'	.006	.026	11.36	8.97	1.26
					N-2	48.'	30'	.008	.021	7.35	5.37	1.36
8-5	1958	3 Simple	PCB	Anchor Rods	E-1	41.8'	30'	.015	.019	10.86	6.69	1.62
					E-2	52.2'	30'	.048	.023	8.06	5.12	1.57
8-6	1954	6 Simple	Comp. Beam	Spiral	W-1	49'	36'	.009	.010	11.37*	5.90	1.92
					W-2	49'	36'	.009	.021	9.80	5.82	1.68
9-31	1963	9 Simple	Comp. Beam	Spiral	W-1	79'	74'	.047	.004	4.78	4.50	1.06
					W-2	79.2'	74'	.043	.009	4.89	4.48	1.09
					E-1	79'	74'	.030	.013	5.19*	4.50	1.15
					E-2	79.2'	74'	.075	.015	4.27	4.48	0.95
1-18	1955	2 Contin.	WPG	Spiral	N-1	120'	36'	.122	.010	2.40	-	-
					N-2	120'	36'	.066	.012	2.40	-	-
4-36	1964	4 Contin.	Monolithic Concrete "T" Beam	-	W-1	35'	48'	[.026]	.012	9.70*	-	-
					W-2	60'	48'	[.146]	.011	8.58*	-	-

TABLE III

Bridge File Number	Year Built	Design Spans	Design Type	Shear Conn.	Span Number	Span Length (Ft.)	Span Width (Ft.)	Relative Displacement Double Amplitude Inches	Damping Coeff.	Measured Frequency (CPS)	Theor. Frequency (CPS)	Ratio Measured / Theor.
1-2	1959	Cant.	Welded	Spiral	S-1 Anchor Span	227	30	.032	.014	2.71*	-	-
		Susp.	Plate Girder		S-2 Cant. Sect	38.5	30	.032	.024	4.72	-	-
1-3	1959	Cant.	Welded	Spiral	E-2 Anchor Span	114	30	.043	.010	2.38	-	-
		Susp.	Plate Girder		E-3 Cant. Sect.	42	30	.077	.012	2.38	-	-
6-3	1955	Cant.	Composite	Spiral	W-1 Anchor Span	65	49	.042	.012	4.54	-	-
		Susp.	Beam		W-2 Cant. Sect.	12	49	.052	.012	4.68*	-	-
					W-3 Susp. Span	52	49	.080	.022	4.54*	-	-
8-2	1959	Cant.	Composite	Spiral	W-1 Anchor Span	103	74	.101	.018	2.55	-	-
		Susp.	Beam		W-2 Cant. Sect.	30	74	.120	.014	2.57	-	-
					W-3 Susp. Span	80	74	.097	.011	2.73*	-	-
9-32	1963	Cant.	Composite	Spiral	S-1 Anchor Span	94	74	.133	.015	3.09*	-	-
		Susp.	Beam		S-2 Cant. Sect.	16.3	74	.154	.015	3.00*	-	-
					S-3 Susp. Span	80.5	74	(.043)	(.007)	(2.54)	-	-

Notes:

(1) Span Length-Measured from center to center of bearings
(2) Span Width- Measured from curb to curb
(3) Amplitude-maximum from peak to peak or double amplitude recorded during testing either at midspan or at the end of cantilever sections. These values are presented to give an indication of the relative movement of the span under a moving load and are not intended to indicate the maximum displacement.
(4) Damping Coefficient is averaged for a series of tests.
(5) Measured Frequency-Lowest repeating frequency measured at midspan or at the end of cantilever sections. When there was no apparent repeating frequency, an average of the frequencies is given. The frequencies in parenthesis indicate a limited number of traces suitable for frequency determination. Frequencies followed by an asterisk indicate average values of the series of test runs. Displacements in brackets were induced under H20-S16 loading.

Consideration also was given to different bridge bearing pads used on the test bridges and to their possible effect on vibrations. Four types of bearing pads were used on the structures studied: a 1/4-inch rolled phosphor bronze plate, a 1/4-inch lead plate, 3 layers of canvas duck with red lead paint, and 1/2-inch "Fabreeka" (cotton duck and rubber). Comparison of the vibration data with pad types indicated that a wide range of frequencies, displacements and damping factors were obtained with each pad type. Consequently, it was concluded that the types of pads used had no significant effect on vibration characteristics. This is perhaps what one might expect because of the relatively thin pads used, compared with the more flexible 2 to 3 inch-thick elastomeric pad, whose affect on vibrations has been found to be significant. (6)

Vibration data also were analyzed with regard to extent and severity of deck cracking observed on bridges of different design. The statewide condition survey indicated, not unexpectedly, that deck cracking was usually found to be more prevalent and severe in the negative moment areas of the continuous and cantilevered suspended spans. The vibration measurements are summarized in Table IV as average values of relative displacements, damping coefficients and measured frequencies noted on simple, continuous and cantilevered suspended spans.

TABLE IV
VIBRATION PARAMETERS VS. BRIDGE DESIGN

Span Type	No of Brgs.	Dynamic Displace. Inches		Damping Coefficient		Measured Freq. Cycles per sec.	
		Avg.	Range	Avg.	Range	Avg.	Range
Simple	11	0.037	.005-.099	0.021	.004-.032	6.95	3.96-16.62
Continuous	2	0.094	.066-.122	0.011	.010-.012	5.77	2.40-9.70
Cantilevered Susp.	5	0.084	.032-.154	0.015	.010-.024	3.32	2.71-4.68

NOTE: Average values are taken from the results in Table III, except values plotted in parentheses and brackets.

Based on the limited test results shown in Table IV the continuous and cantilevered suspended spans had, on the average, approximately 2 1/2 times the magnitude of dynamic displacement found on simple spans. Moreover, their average damping coefficients were one third to one half less, indicating that they generally vibrated for longer periods than the simple span structures. To conclude, however, that these parameters are related to cracking on the deck surface would be mere conjecture. Other information not known must also be considered in such a correlation. For example, the dynamic displacements do not take into consideration static displacements, which presumably would be greater for simple span structures, assuming everything else equal. Therefore, simple spans could have greater total displacements even though dynamic values are less.

An important observation noted during the vibration studies was the transmission of vibrations through common abutments and piers supporting adjacent spans or twin bridges. In one test run on twin cantilevered suspended bridges, a relative peak to peak displacement of .013 inches was measured on the unloaded structure from vibrations transmitted through a common pier bent. This phenomenon suggests that measureable movements of structures can occur from vibrations induced by traffic on adjacent bridges. Therefore, when a structure is to be closed to traffic for repair or reconstruction, this fact should be taken into account because of its possible effects on concrete strength development.

Bridge Deck Surface Roughness

A study of surface roughness on ten bridge decks was conducted with the Bureau's Roughometer in an attempt to correlate surface roughness with cracking of the deck. The structures included a variety of design types, ages, wearing surfaces and condition. Table V presents the test results, which indicate that all the bridges tested had a surface roughness index greater than 120 inches per mile. In accordance with the BPR classification, values over 120 ipm are considered poor for pavements. However, these values of roughness are not unusual for bridge decks. Nevertheless, no correlation was found with bridge deck deterioration.

Core Samples and Tests

Following the preliminary condition survey in 1964, 47 of the 54 bridge decks selected for detailed studies were cored. The samples were visually examined and tested in the laboratory. Figure 14 shows the geographical location of cored bridges. The cores included 114 from portland cement concrete wearing surfaces, 33 from bituminous concrete wearing surfaces, and 108 from structural concrete decks.

TABLE V

BRIDGE DECK ROUGHNESS DATA

DESIGN	WEARING SURFACE	INSPECTION SURVEY	AGE (YRS.)	AVE. BPR ROUGHNESS INDEX	BPR CLASSIFICATION
Composite I-Beam	Portland Cement Concrete	Severe Scaling - Moderate traffic Light Cracking on Surface and Underside	5	128.7	Poor
Composite I-Beam	Bituminous Concrete	Light Cracking on Structural Slab	3	156.2	Poor
Precast Concrete Beam	Portland Cement Concrete	Moderate Cracking on Surface	6	245.9	Poor
Composite-Continuous Plate Girder	Portland Cement Concrete	Light scaling, moderate cracking on surface. Slab severely cracked.	9	208.8	Poor
Cantilevered Suspended Plate Girder	Portland Cement Concrete	Severe cracking on wearing surface	6	132.6	Poor
Arch Suspension	Portland Cement Concrete	Medium transverse cracking on surface	6	162.4	Poor
Cantilevered Suspended Plate Girder	Portland Cement Concrete	Medium transverse cracking on surface	6	286.9	Poor
Composite I-Beam	Portland Cement Concrete	Light scaling, light cracking on surface	15	154.5	Poor
Composite I-Beam	Bituminous Concrete	Light cracking on underside	5	159.5	Poor
Composite I-Beam	Portland Cement Concrete	Severe transverse cracking	5	121.3	Poor

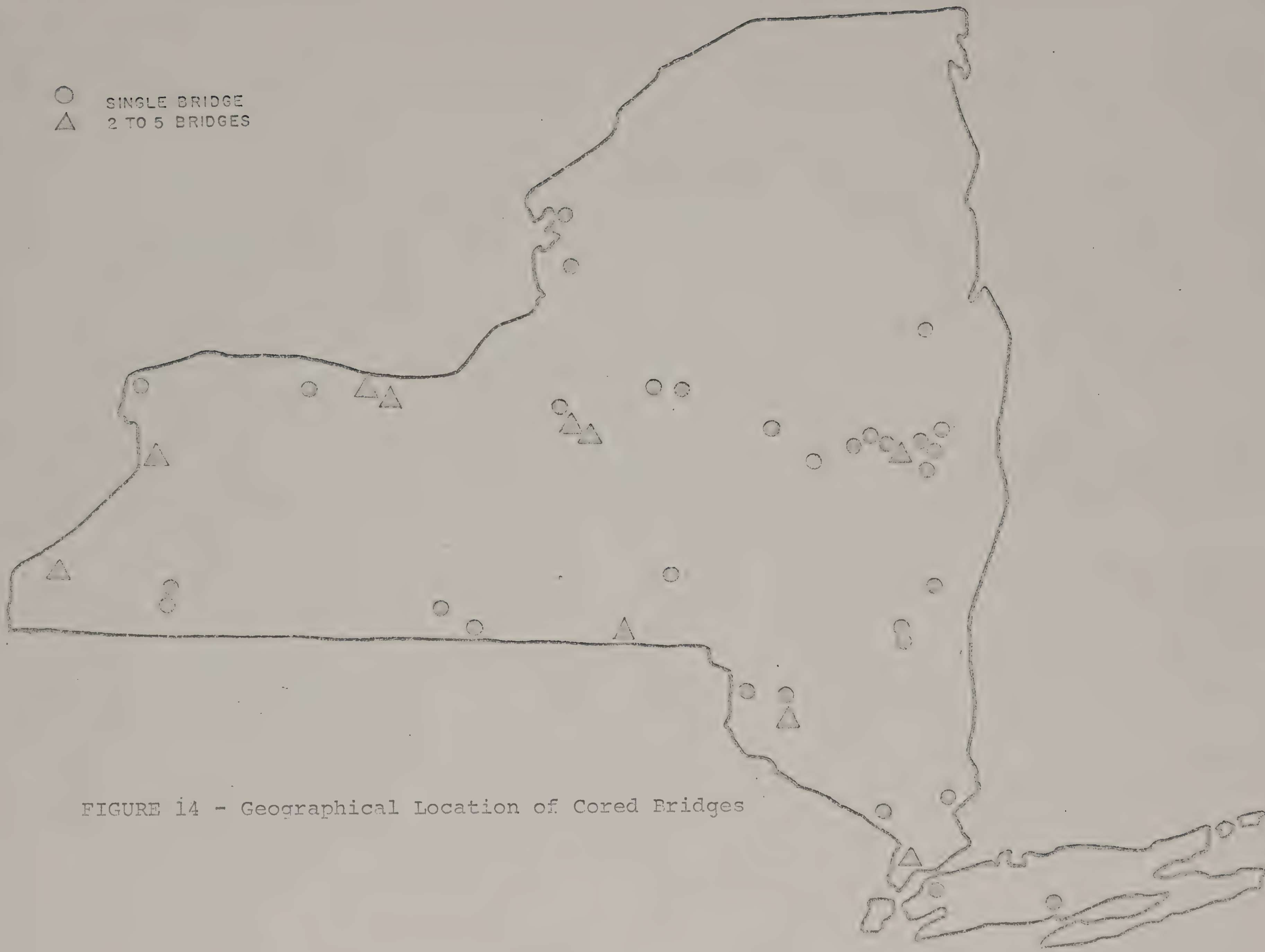


FIGURE 14 - Geographical Location of Cored Bridges

Bond Between Concrete Courses - During coring operations, the extent of bond between the two-course concrete decks was determined. Approximately 50 percent of the samples indicated the existence of bond sufficient to require some effort to break apart. Eight of these samples were so well bonded that the plane or bond line between courses was difficult to locate visually. The majority of unbonded specimens had a bituminous sealer or bond breaker between courses. In many cases upon removal of unbonded samples, a space of from 1/8 to 1/2 inch could be observed between courses, in the cored hole. It appears that the lack of bond permitted the concrete wearing course to act independent of the structural slab and, therefore, warp under certain conditions of temperature and moisture. Once cracking occurs in the wearing course, water and de-icing chemical gain access to the structural slab and accelerate deterioration. As a result, cracking of the wearing course can eventually occur due to the inability of the unsupported 4-inch wearing course to carry heavy wheel loads. This factor together with the ingress of moisture and de-icing salts can result in rapid deterioration of concrete decks.

Concrete Cover Over Steel Reinforcement - Concrete cover over steel reinforcement was measured on cored samples to determine if specified cover was being attained in practice. Contract plans called for one to two inches of concrete cover over 6 x 6 x 6 welded wire fabric in the 4-inch portland cement concrete wearing surface, and one inch cover over reinforcing steel in the 7-inch structural slab. Approximately 60 percent of wearing course samples had 2.6 inches of cover and only 2 percent with cover less than one inch. Eighty-four percent of the structural slab cores had 1.5 inches or more cover, while only 10 percent had less than one inch. Thus, the specified cover over concrete steel reinforcement has usually been obtained in concrete bridge deck construction.

Corrosion of Steel Reinforcement - A visual inspection for corrosion of reinforcing steel was made after the core samples were processed for salt tests. In all but one sample, corrosion consisted of a light coating of rust, which could have existed on the steel reinforcement prior to embedment in the concrete. Severe corrosion was noted on one sample which was extracted from a 10-year old bridge deck with a 2 1/2-inch bituminous concrete wearing surface. Discussions with maintenance personnel indicated that this structure was heavily salted particularly during the first winter after construction. While the severe corrosion cannot be completely explained, the heavy salting probably was a contributing factor.

Air Content Measurements - Total air contents of cored samples were determined by the high-pressure air meter method, which is described fully by the Portland Cement Association(5). The test method used was in close agreement with the prescribed procedure, with one exception: water was forced into the pores of the concrete at a pressure of 4000 psi instead of 5000 psi noted in the PCA method.

Total air contents, as determined by the high-pressure method, take into account the air content of all voids in the concrete including those in the aggregates, as well as entrapped and entrained air in the mortar. Since entrained air contents are more indicative of concrete performance than total voids, four samples tested by the high-pressure air meter method were examined for entrained air by linear traverse. Results are given in Table VI. Total air measurements by the high-pressure method agreed closely (within 1 percent air) with total air and entrained air measurements by the linear traverse for all specimens except sample 5-17-1. The large differences (2.9-4.9 percent air) for this sample were attributed to the presence of slag aggregate.

A summary of air-test measurements determined on 103 samples by the high-pressure air meter is given in Table VII. The samples are grouped into two major categories: air entrained concrete (concrete with specified air content) and non air entrained concrete (concrete without specified air content). These are further separated into samples from wearing courses and from structural decks.

Although there was a wide range of air content values for each group of samples, their respective mean value was within the specified air content range of 3.0-6.0 percent. An important note of interest is that 59 percent of the wearing course samples of non air-entrained concrete were within the air content range of 3.0-6.0 percent specified for air entrainment, while the wearing course samples of air-entrained concrete included only 37 percent within the specified range. This demonstrates that the specified air contents were not always obtained, and further, that in many cases air was entrained in "non air-entrained" concrete. Both findings help to explain the observation in Part I that air-entrained concrete wearing courses performed no better than those with non air-entrained concrete.

Sodium Chloride Measurements - A chemical analysis for sodium chloride content was conducted on 114 core samples, (56 Portland cement concrete wearing surfaces and 58 concrete structural slabs), to determine the salt gradient in the concrete. For comparison, three concrete cores extracted from a new structure and three 6" x 12" test cylinders cast during construction at

TABLE VI

COMPARISON OF AIR TEST MEASUREMENTS USING HIGH PRESSURE AND LINEAR TRAVERSE METHODS

Core No.	Specified Air Content (%)	High Pressure Method Total Air (%)	LINEAR TRAVERSE METHOD						
			Total Air (%)	Entrained Air (%)	Ave. Chord Length (in)	Voids Per Inch	Paste Content (%)	Spacing Factor (in)	Traverse Direction
1-35-3	3.0-6.0	8.5	9.66	8.05	.005139	18.7920	26.63	.0035	Trans 1" below surf.
5-17-1*	None	12.5	9.59	7.65	.004905	19.5431	26.43	.0034	Long 4" depth
9-17-2	3.0-6.0	2.4	2.78	1.62	.009904	2.8056	21.00	.0096	Long 3 3/4"
9-21-2	None	2.8	2.71	2.06	.007051	3.838	22.02	.0071	Long 4" depth

Note: *Concrete contained a slag aggregate, which accounts for the large difference between measurements by each method.

TABLE VII

AIR TEST RESULTS
(HIGH PRESSURE AIR METER)

	AIR ENTRAINED CONCRETE (1)		NON AIR ENTRAINED CONCRETE (2)	
	Wearing Course	Structural Deck	Wearing Course	Structural Deck
Number of Cores	24 (3)	24 (3)	27	28
Range of Air Values (%)	1.0-8.6	1.4-7.4	1.9-12.5	0.7-9.7
$\overline{X}$ - Arithmetic mean (%)	4.4	3.6	5.1	3.4
δ - Standard Deviation (%)	2.2	1.5	2.2	1.9
% Samples within 3.0-6.0% Air Content	37	50	59	35

(1) Concrete with specified entrained air
(2) Concrete without specified entrained air
(3) Two cores with concrete conforming to 1962 New York State Specifications

The remaining samples conform to 1957 New York State Specifications

NOTE:

1957 New York State Specifications called for 3.0-6.0% entrained air, 4.5-5.0% desired.

1962 New York State Specifications call for 6.0-9.0% entrained air, 7% desired in concrete with #1 maximum size aggregate.

the site, were also tested to determine sodium chloride content in concrete not subjected to de-icing chemicals. The salt samples represented concrete taken from horizontal sections at approximately 1/2, 2 and 3 1/2 inch depths of the wearing course and 1/2, 1 and 3 1/2 inch depths of the structural slab.

The usual procedure for extracting samples for the sodium chloride test consists of sawing horizontal slices of the core at each specified depth, then crushing each slice and removing the coarse aggregate particles manually. The crushed material is then ground to pass a #30 sieve for the chemical test. This method of sample preparation was tried and discontinued in favor of a modified procedure, which was considered to be more advantageous. It consisted of placing the core on its side and extracting a 50 gram sample with a three-eighths inch masonry drill. The main advantages of this method are ease in sample removal and elimination of crushing and grinding. Moreover, the drilling method does not require wash or cooling water used in sawing which undoubtedly removes a substantial portion of the free salt to be measured.

A disadvantage inherent in the drilling method is the inability to remove coarse aggregate particles which may contain soluble chlorides not attributed to the infiltration of de-icing chemicals. However, the amount of chlorides from this source is not considered significant for this investigation.

The quantitative analysis test procedure used for determining soluble chlorides was taken from the Standard Methods of Chemical Analysis by Scott, 6th Edition. Basically, the test method determines the sodium chloride content by a titration process using a silver nitrate solution. The test procedure, typical computations, and test results are included in the Appendix.

Test Results - In an attempt to correlate degree of scaling with air and salt contents, the test results from 26 cores of concrete wearing surfaces were tabulated and analyzed. Table VIII summarizes the results in four categories of scaling: none, light, moderate and severe, with corresponding range and average values for salt and air contents. Air content values represent percent total air by volume as determined by the high-pressure air meter. The salt content was measured in the top one-half inch of the core and expressed as a percent of the total weight, including coarse aggregate.

A review of the test data in Table VIII indicates a wide range of salt and air content values for each of the four scaling categories, with no correlation between severity of scaling and either air content or concentration of salt. This suggests that other factors not included in the data, i.e. air void

TABLE VIII

SCALING VS. AIR and SALT CONTENTS

Number of Bridges Sampled	Scaled Condition of Deck	Total Air Content[1]		Salt Content[2]	
		Range, %	Ave., %	Range, %	Ave., %
9	None	2.2-12.5	5.3	.014-.690	.263
9	Light	2.1-8.5	5.1	.084-.407	.239
4	Medium	2.3-7.9	4.2	.098-.395	.199
4	Severe	5.2-7.2	5.7	.181-.706	.331

1 Based on high-pressure air meter method

2 Salt content of top 1/2-inch slice expressed as a percent of total weight of slice.

characteristics, type of aggregate, design mix, and history of salting must be considered in the evaluation of scaling. Another factor is that the air content measurements represent the entire depth of the core, and not necessarily that obtained at the surface.

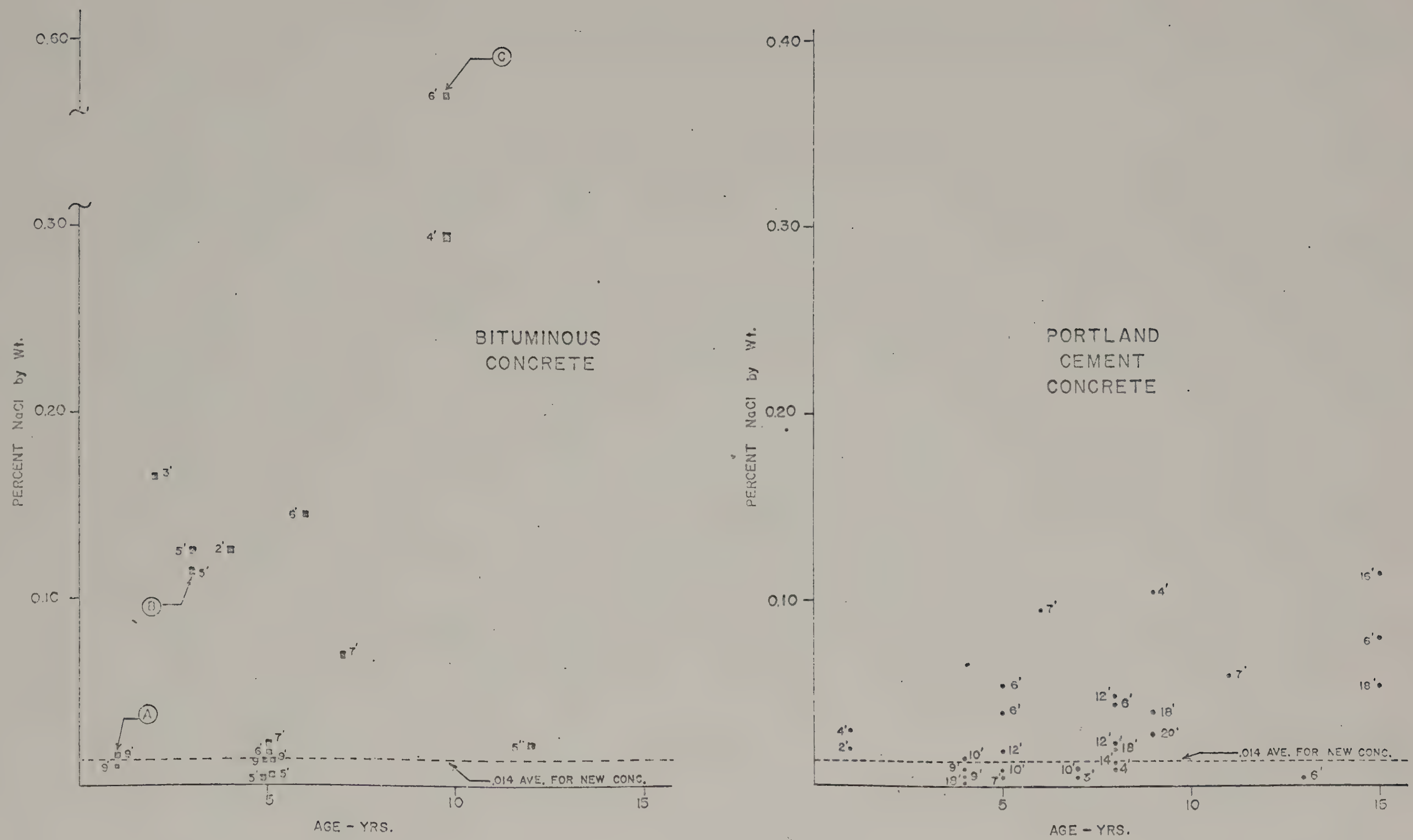
An additional study was made to determine differences, if any, in the salt content of the top half inch of the structural concrete deck with a portland cement or bituminous concrete wearing surface. Figure 15 presents the core samples plotted with respect to age, type of wearing course, salt content and distance from the curb. As expected, the salt content was usually higher at points nearest the curb, where moisture normally collects due to the crown of the surface. It also appears that structural decks with bituminous concrete generally contain more salt than those covered with a portland cement concrete. Undoubtedly, this is due to greater infiltration of salt-laden surface water through the relatively porous bituminous concrete surface and subsequent ponding on the structural deck. Further, data presented in the Appendix shows a marked decrease in chloride content with depth below the concrete surface.

Three samples were taken from cores with concrete protective coatings. One of these coatings is a polyester resin placed as an interlayer or membrane between the structural deck and the bituminous concrete overlay, while the other two were epoxy asphalt coatings on the bituminous concrete wearing surfaces. These samples are identified in Figure 15 as A, B, and C.

A comparison of the samples from coated decks with those without coatings of similar age, shows little difference in salt content. The epoxy asphalt surface coatings appear to offer no protection against salt penetration into the concrete after 3 yr service. From this data, it is not possible to draw conclusions regarding the polyester resin membrane because it was only one year old at the time of sampling and the salt content was no less than a similar deck without a membrane.

Discussion of Test Results

The purpose of this phase of the study was to determine possible causes for some of the types of bridge deck deterioration observed. In summarizing the test results, it was apparent that the findings did not reveal any unusual or extraordinary information. Unfortunately, much of the vibration data was of limited value because of difficulties in analyzing the dynamic effects produced by uncontrollable normal traffic. Examinations and laboratory tests of extracted concrete cores, however, did provide evidence to substantiate previous theories that were based mainly on supposition.



A. 1-yr-old ployester resin membrane coating.
B. 3-yr-old epoxy-asphalt surface coating.
C. 10-yr-old epoxy-asphalt surface coating.

Figure 15. Sodium chloride content of top 1/2-in. of structural deck, in relation to age, location (distances given indicate feet from curb), and type of wearing course.

During the bridge vibration tests, it was noted that vibrations of measurable magnitudes can be transmitted through bridge piers and abutments. This suggests that consideration be given to the possible damaging effects of normal traffic vibrations on concrete construction being conducted in adjacent spans or twin bridges using common footings. Although there was no evidence from this investigation that concrete damage had occurred because of this, further study is needed to determine if traffic vibrations can affect the setting of fresh concrete during the initial hardening period.

Examination of cores removed from the two-course portland cement concrete decks indicated that the existence of a bond between courses was associated with a reduction in wearing course cracks. Usually, the unbonded specimens were found in the more severely cracked areas. Inspection of the core holes revealed that the unbonded specimens usually had a 1/8 to 1/2-inch space between courses which could result in high stresses and subsequent cracking in the unsupported wearing course. It appears, therefore, that the use of a monolithic concrete deck could eliminate this problem.

The cores indicated that only ten percent of the samples with reinforcement had less than the specified minimum concrete cover of one inch, while 84 percent had 1 1/2 inches or more. With one exception, steel corrosion was limited to light rust which could have existed on the steel prior to embedment in the concrete. This is good evidence that the concrete cover specified is sufficient to protect the reinforcement.

A review of the salt contents measured in the top 1/2-inch of the structural concrete decks revealed two important points.

1. More salt was found in decks covered with bituminous concrete than in those with portland cement concrete.

2. After 3 yr service, two asphalt epoxy surface coatings offered no protection against salt penetration.

The bituminous concrete permits more salt-laden moisture to permeate the deck beneath than the concrete wearing surface. As a result, more concrete deterioration might be expected beneath bituminous concrete surfaces. Therefore, unless adequate protection is provided by some type of coating, serious deterioration can occur in the structural concrete deck which will be camouflaged by the wearing surface.

CONCLUSIONS

1. Normal traffic loading produced dynamic vibrations that were difficult to analyze and could not be correlated with bridge deck deterioration.

2. The thin bearing pads used on the bridges studied had no damping effect on vibrations.

3. Traffic vibrations of measurable magnitudes can be transmitted to unloaded spans and adjacent structures through common piers or abutments.

4. Air content measurements as determined by the high-pressure meter are in generally close agreement with those obtained by the linear traverse.

5. Air contents within the specified range of 3.0 to 6.0 percent were obtained in only 37% of the concrete wearing courses and 50% of the structural decks sampled.

6. More salt is found in the top 1/2-inch of structural decks covered by bituminous concrete than in those with portland cement concrete wearing courses.

7. Based on the service performance of two bridges, it appears that asphalt epoxy coatings used as wearing surfaces offer little protection against salt penetration after 3 yr service.

PART III: DECK PROTECTIVE COATINGS

This part of the report evaluates the performance of protective coatings applied to approximately 170 concrete bridge decks in New York State from 1961 to 1965. The materials included a variety of products, the majority of which contained plastics such as epoxies and polyesters. Also included were a few applications of polyurethanes, latexes, neoprenes and silicone rubbers. Table IX shows the number and types of coatings inspected during the period of study from 1963 to 1966.

Some of these coatings were placed as part of the regular contract for construction of the bridge while others were applied to existing structures strictly for experimental purposes. Each group will be discussed separately because little information is available on the contract coatings as to surface preparation or application, whereas extensive observations and measurements were made by research personnel on the placement of the experimental coatings by the manufacturers.

Coatings were classified as follows according to their intended purpose.

Membranes are used in two-course deck construction between the structural slab and the wearing course. They may vary in thickness from a few mils to 3/8-inch and are designed to protect the structural slab from water and de-icing chemicals.

Surface Overlays also serve to prevent infiltration but are placed on top of the wearing course. Consequently, they must withstand more severe environmental conditions. In some cases the materials used for surface overlays are similar to those used as membranes, except for modifications which are required to improve their skid resistance and wearing properties.

Surface Sealants are applied to portland cement concrete for protection from water and de-icing salts. Basically, they act as dampproofers by retarding rather than preventing the passage of water and therefore allow the concrete to breathe. Their life expectancy is short in comparison to the membranes and surface coatings, and reapplication is necessary at frequent intervals.

The tabulations in Table IX indicate that the total number of coatings inspected reached a maximum in 1965 (170) and of these over 58 percent consisted of polyester resin membranes. A lesser number, but of significant magnitude, included the

TABLE IX
BRIDGE DECK PROTECTIVE COATINGS
Inspected 1963 - 1966

Coating Material	Membrane				Surface Overlay				Surface Sealant			
	'63	'64	'65	'66	'63	'64	'65	'66	'63	'64	'65	'66
Contract Items												
Polyester Resin w/Fiberglas	56	87	99	101	2	2	2					
Bituminized Epoxy (A)	5	8	8	8	4	14	20	19				
Epoxy Resin					2	3	3	3				
Bituminized Epoxy (B)[1]				1			4	5				
Modified Cutback Asphalt	3	4	4	4								
Distillate Oil										1	1	1
Silicone, Water-Soluble										15	15	16
Experimental Items												
Linseed Oil[2]									1	3	3	3
Bituminized Epoxy (A)					1	1	1					
Neoprene-Hypalon Rubber					1	1	1	1				
Silicone Rubber						1	2	2				
Polyester Resin w/Fiberglas							1	1				
Polyurethane Resin							1	1				
Stabilized Rubber Vinyl Pitch							1	1				
Latex-Mortar[3]					3	3	3					
Urethane-Mortar[3]					1	1	1					
Totals	64	99	111	114	14	26	40	33	1	19	19	20

1 More flexible system than Bituminized Epoxy A
2 50-percent mixture of boiled linseed oil and mineral spirits, applied only to sidewalks, curbs, and sidewalls.
3 Cement-mortar overlay with admixtures.

bituminized epoxy "A" surface coating, 12 percent, and the silicone sealants, 9 percent. A differentiation is made between bituminized epoxy systems with regard to flexibility. The more rigid system is designated as the (A) type. Materials are described in general chemical terms, although they include a number of proprietary products that differ slightly from each other.

Inspection Procedure and Types of Distress Noted

Coating inspections were conducted by a project engineer and technician, who surveyed the top and bottom of each bridge deck and mutually agreed upon the condition. Since the surface overlays were visible, they were easily classified as: good, delaminated due to poor bond, cracked or bleeding.

Because membrane coatings were beneath a bituminous concrete wearing course, very little information concerning coating performance could be obtained from a visual inspection of the deck surface. Consequently, performance was predicated on an inspection of the underside of the deck for signs of leakage and efflorescence which would indicate that the coating was permitting infiltration. Figure 16 shows examples of types of distress noted on deck surfaces, and Figure 17 those observed from below.

Survey Results - Contract Construction

Inspection results of coatings placed by contract are shown in Figures 18 through 20 for the years 1965 and 1966. The 1966 survey illustrates the increase in distress during the most recent one-year period. The extent of distress noted as a percent of bridges sampled does not take into account the degree of distress.

The results of the inspection survey of the surface overlays is shown in Figure 18. For example, during the 1965 inspection, 2 of 3 bridge decks with epoxy resin coatings had either poor bond or cracks, while none were in good condition after an average of 3.7 years. An unexpected situation was noted in the 4 bridges with the more flexible bituminized epoxy B system. Two of them or 50 percent of the sample had coatings that cracked after an average of 1 year. It was expected that the more flexible system would resist cracking, but this was not the case. The two polyester resin coatings failed in all respects after 3 years service. An increase in distress was noted in 1966 for all surface coatings.

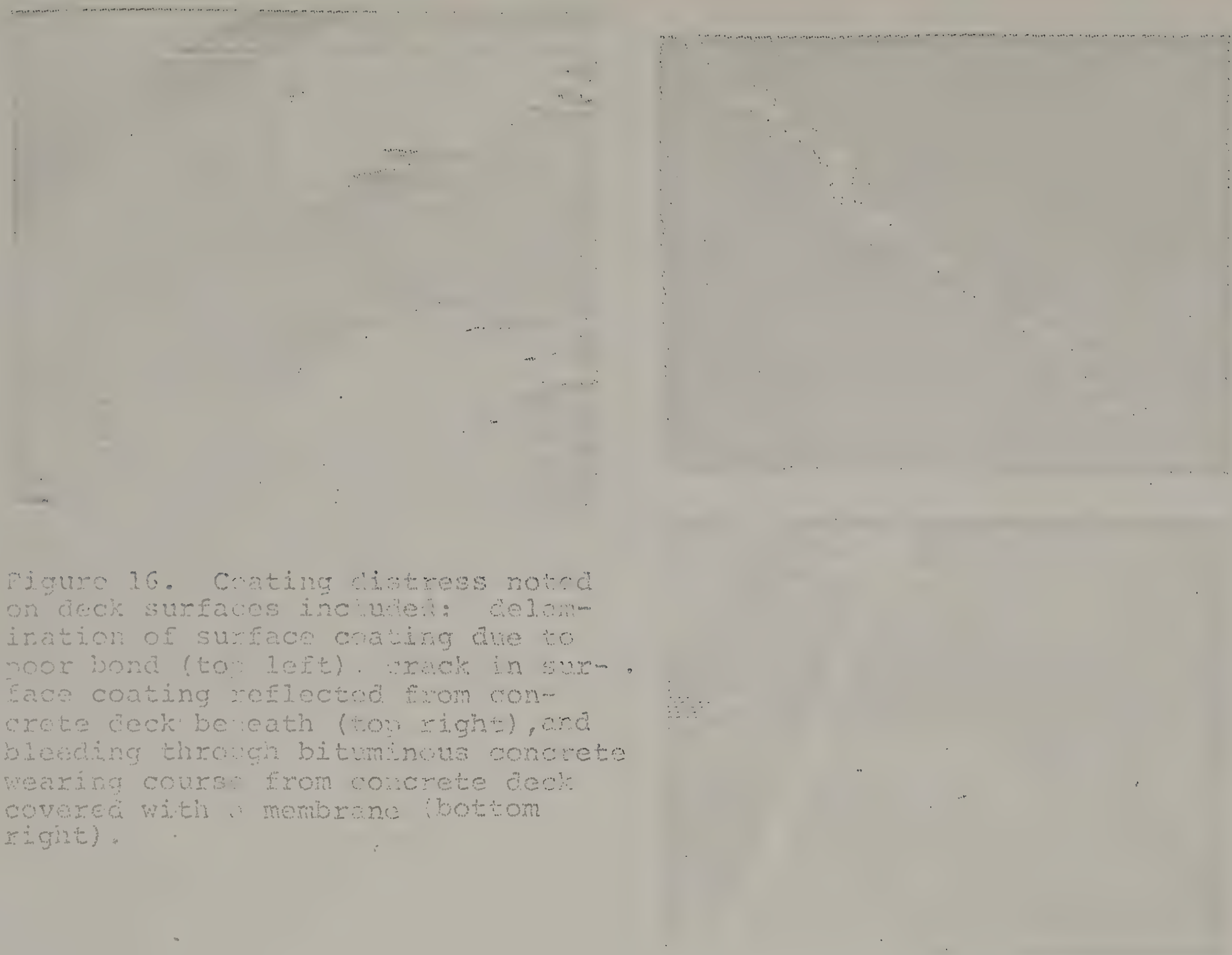


Figure 16. Coating distress noted on deck surfaces included: delamination of surface coating due to poor bond (top left), crack in surface coating reflected from concrete deck beneath (top right), and bleeding through bituminous concrete wearing course from concrete deck covered with a membrane (bottom right).

Figure 17. Conditions noted beneath box beam bridge decks covered with membrane coatings, included leakage between beams (left), and efflorescence between beams (right).

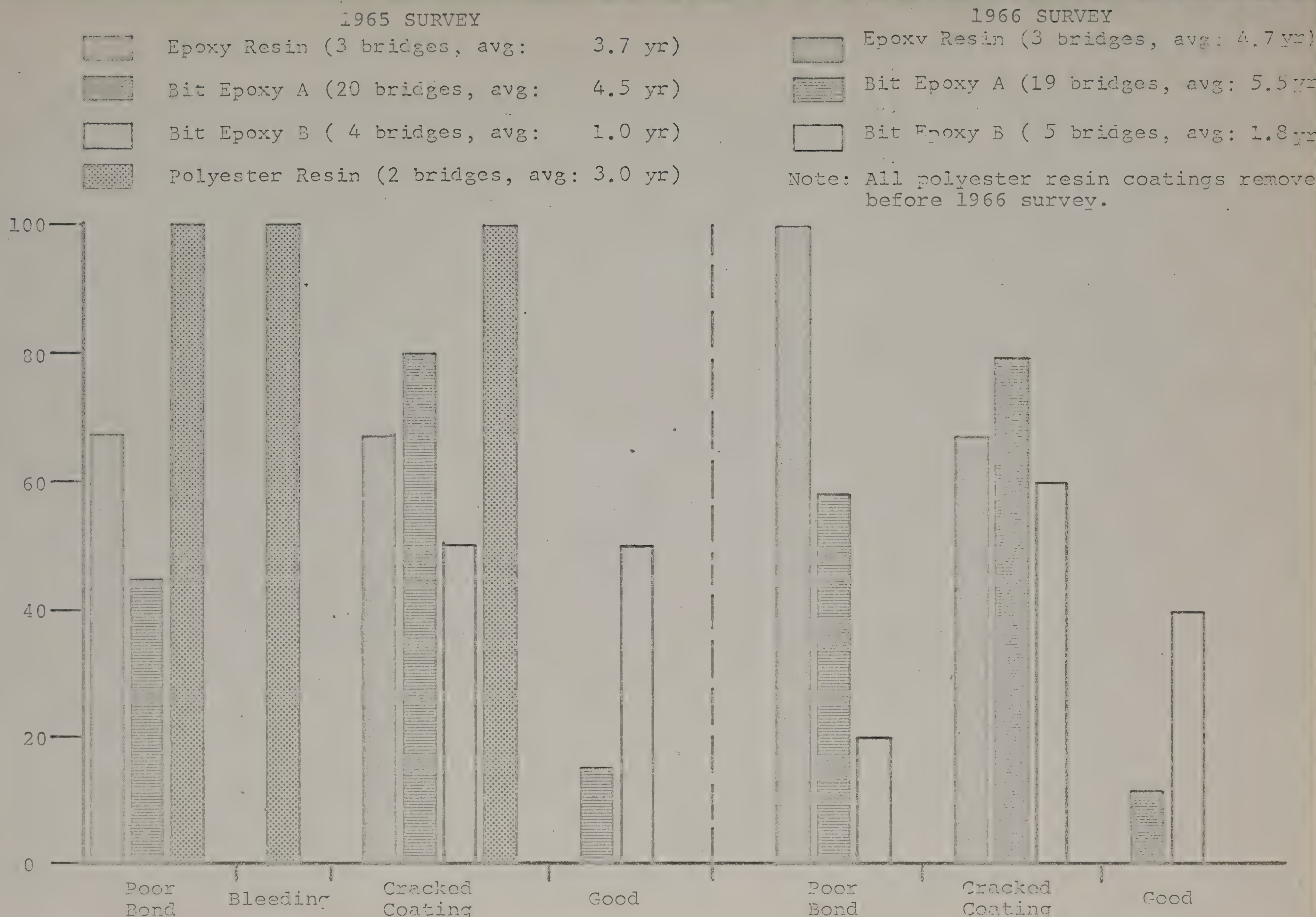


Figure 18. Condition of surface overlays in 1965 and 1966 surveys.

It is interesting to note that in 1965 the underside of decks with surface coatings revealed little evidence of leakage, even though the majority of the overlays had developed some form of distress (Fig. 18). However, the 1966 survey indicated an increase in the percentage of bridges exhibiting leakage. This suggests that all the structures could eventually show signs of leakage.

The underside inspection results of bridges with membrane coatings are shown in Figure 19. Only the polyester resin membranes appeared to be permitting leakage in 1965 after an average of 3.2 years. This condition occurred in 31 percent of the sample (31 of 99 bridges). In 1966, the number of bridges with leakage had increased and these included the bituminized epoxy "A" and modified asphalt cutback coatings as well as the polyester resins.

Since bridges with polyester membrane coatings were the only ones exhibiting leakage in the 1965 survey they were examined further to determine if some feature of the bridge design could account for the distress. Figure 20 shows a comparison of the condition of coated bridges of precast concrete and composite construction. It can be seen that the precast concrete bridges with polyester resin membranes had over 4 times the number of leaking bridges as those of composite design. This fact, together with the better performance of the bitumized epoxy "A" and modified asphalt cutback materials applied only to bridges of composite design, led to a special study of coatings on precast concrete bridges, which is described later in this report.

Silicone and distillate oil sealants were included in the survey mainly to determine their long-time effectiveness in deterring bridge deck deterioration, and not to provide a comparison between sealants and plastic coatings. The survey included 16 non-air-entrained concrete bridge decks, 15 with silicone and one with distillate oil, all placed about 1955. When the initial survey was conducted in 1963, 7 of the 16 structures had been resurfaced with a bituminous concrete wearing course, apparently, because the portland cement concrete had developed distress. The remaining structures showed considerable spalling and cracking on the original concrete surface. By 1966, the majority of these latter structures had been resurfaced with a bituminous concrete, which prevented further inspections. It appears therefore, that the silicone and distillate oil treatments did not significantly improve the durability of the concrete decks.

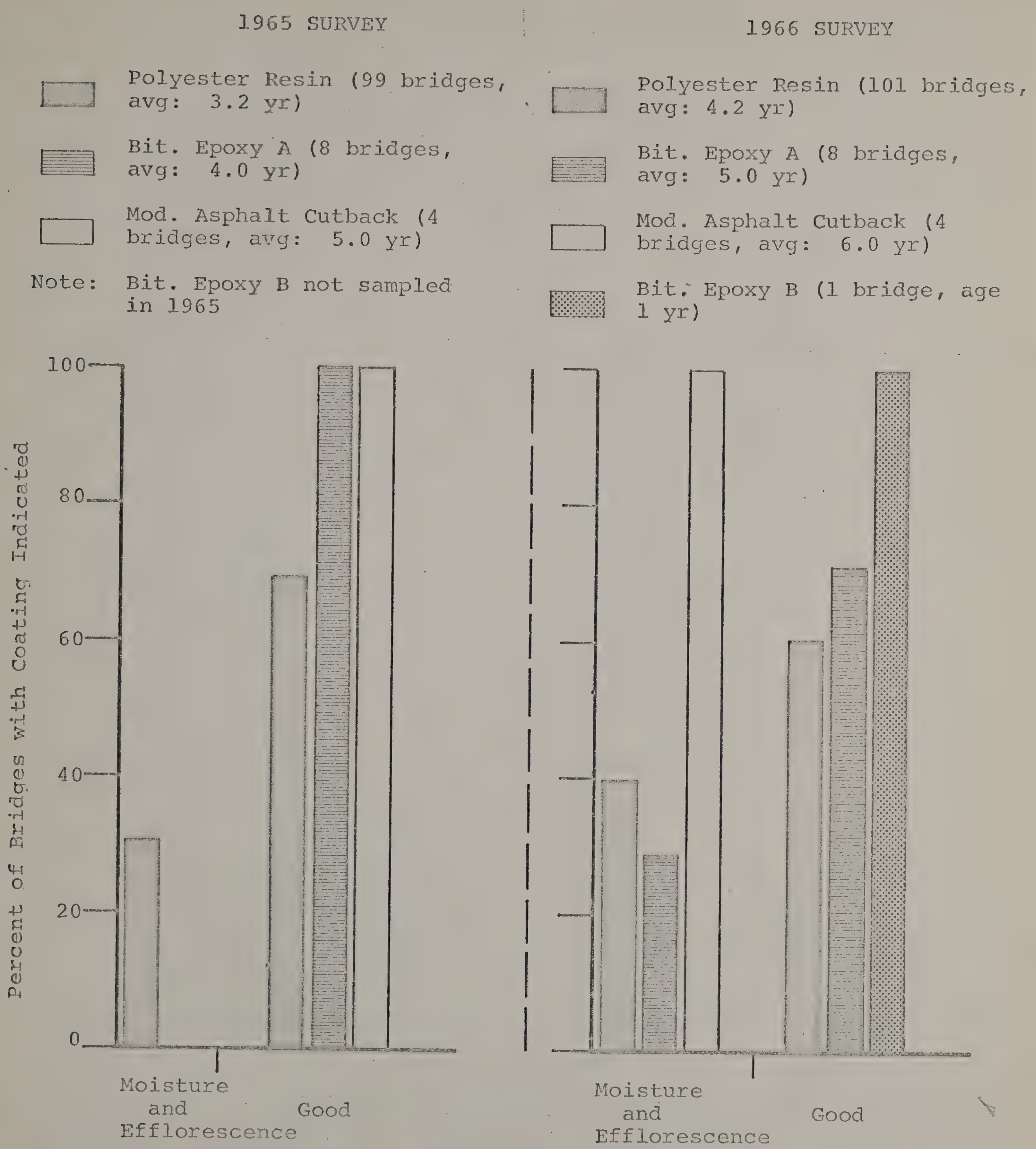


Figure 19. Condition of undersides of bridge decks containing laminar membranes.

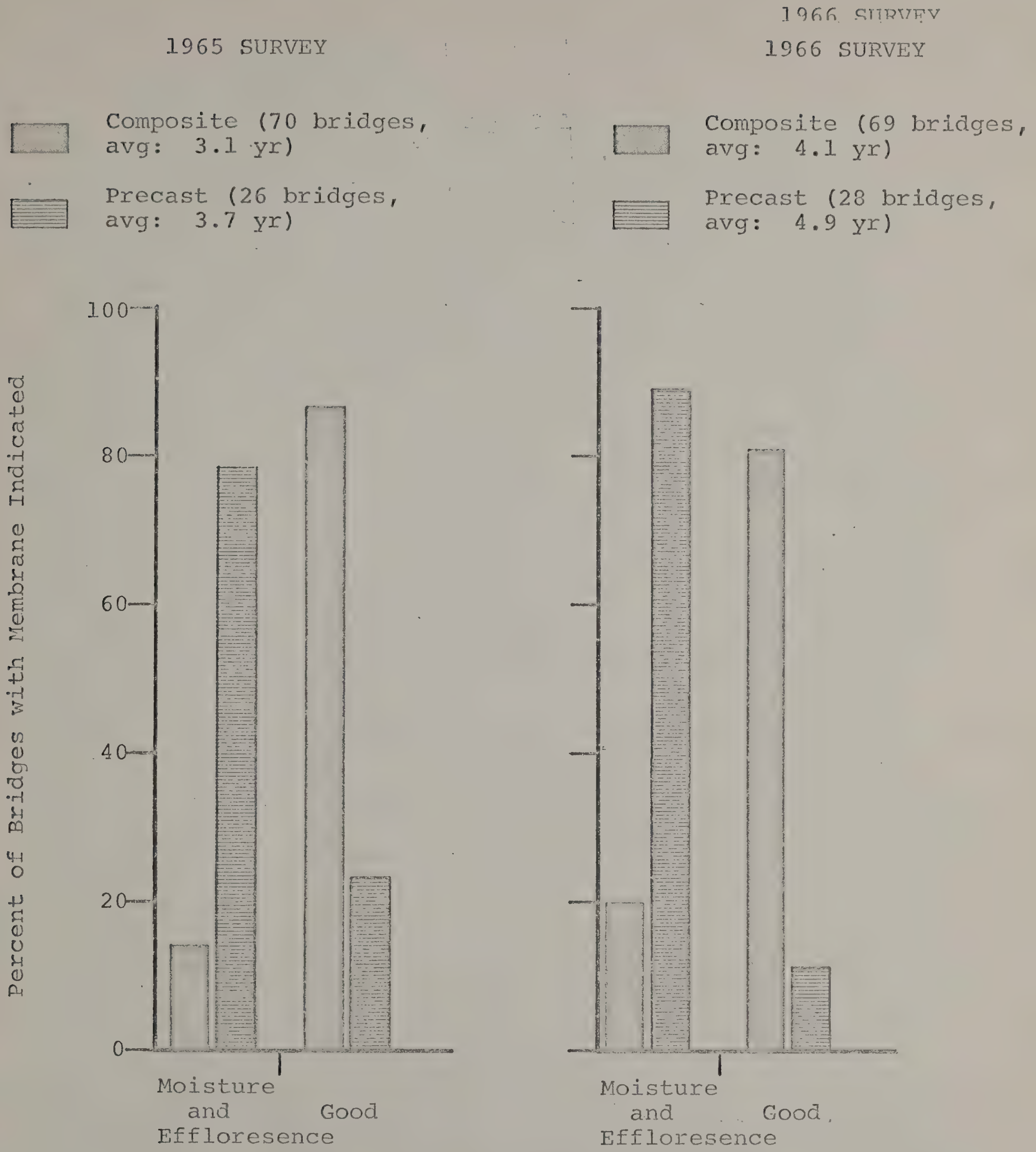


Figure 20. Condition of undersides of composite design and precast concrete bridge decks containing polyester resin membranes.

Special Studies of Contract-Specified Membranes

Composite-Beam Bridges

As noted previously, performance of membrane coatings was judged only on the general condition of the underside of the bridge deck. Wet spots and/or efflorescence were interpreted as indicating that the coating permitted ingress of moisture and, therefore, did not protect the concrete, while absence of moisture suggested that the coating was performing well. Since this criterion for evaluating membrane effectiveness was based on indirect evidence, it was considered necessary to investigate some membranes by removing portions of several bridge deck wearing courses for examination. Accordingly, one-foot square sections of bituminous concrete wearing courses were removed in September, 1963, from the decks of 15 composite-beam bridges, 5 of which had modified asphalt cutback membranes, 3 had polyester resins with fiberglas, and 7 had bituminous epoxy "A" type materials. Inspection revealed the following information.

Modified asphalt cutback membranes (NYS Item 361D) had little or no bond with the concrete slab. Upon removal of the wearing course, the membrane usually adhered to it, exposing the concrete. This lack of bond is believed to have occurred because cured asphalt cutbacks soften at temperatures between 160 to 200°F, while plant mixed bituminous concrete is applied at temperatures ranging from about 240 to 270°F. It follows, therefore, that the bituminous concrete upon application, softens and penetrates the membrane, disturbing its bond with the concrete deck. However, there was no evidence that the continuity of the membrane was destroyed. The condition of the exposed concrete in all cases was found to be excellent, as illustrated in Figure 21. On some decks, the surface of the structural slab exhibited dampness, while the underside was dry.

The polyester resin membranes when exposed showed excellent bond to both the concrete slab and the bituminous concrete wearing course. Sampled sections were so well bonded that portions of the wearing course delaminated and remained with the membrane. After removal of the wearing course, the polyester resin was found intact and in excellent condition, as illustrated in Figure 22. Removal of the membrane indicated that the underlying concrete slab was dry and sound. In all cases the underside of the structural slab also was dry and gave no evidence of leakage or cracking.

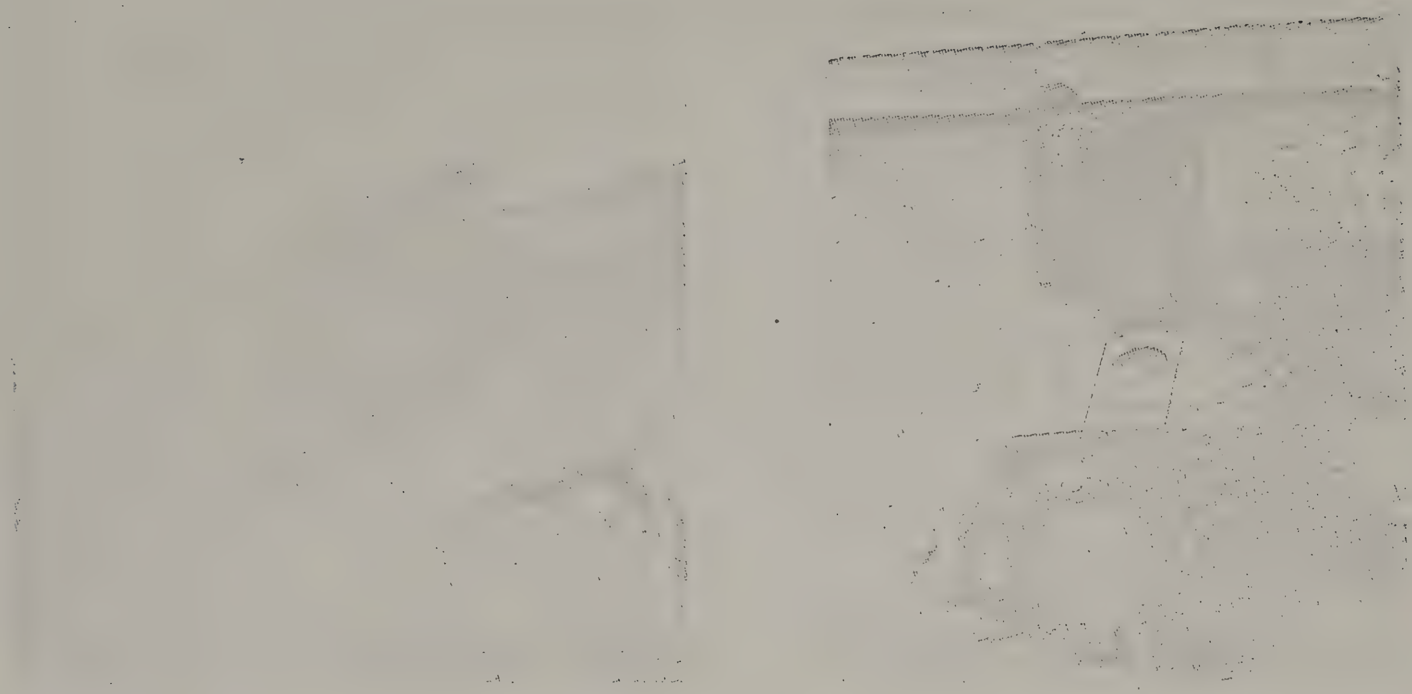


Figure 21. Removal of bituminous concrete wearing course, with asphalt cutback membrane bonded to it, exposing underlying concrete slab in good condition.

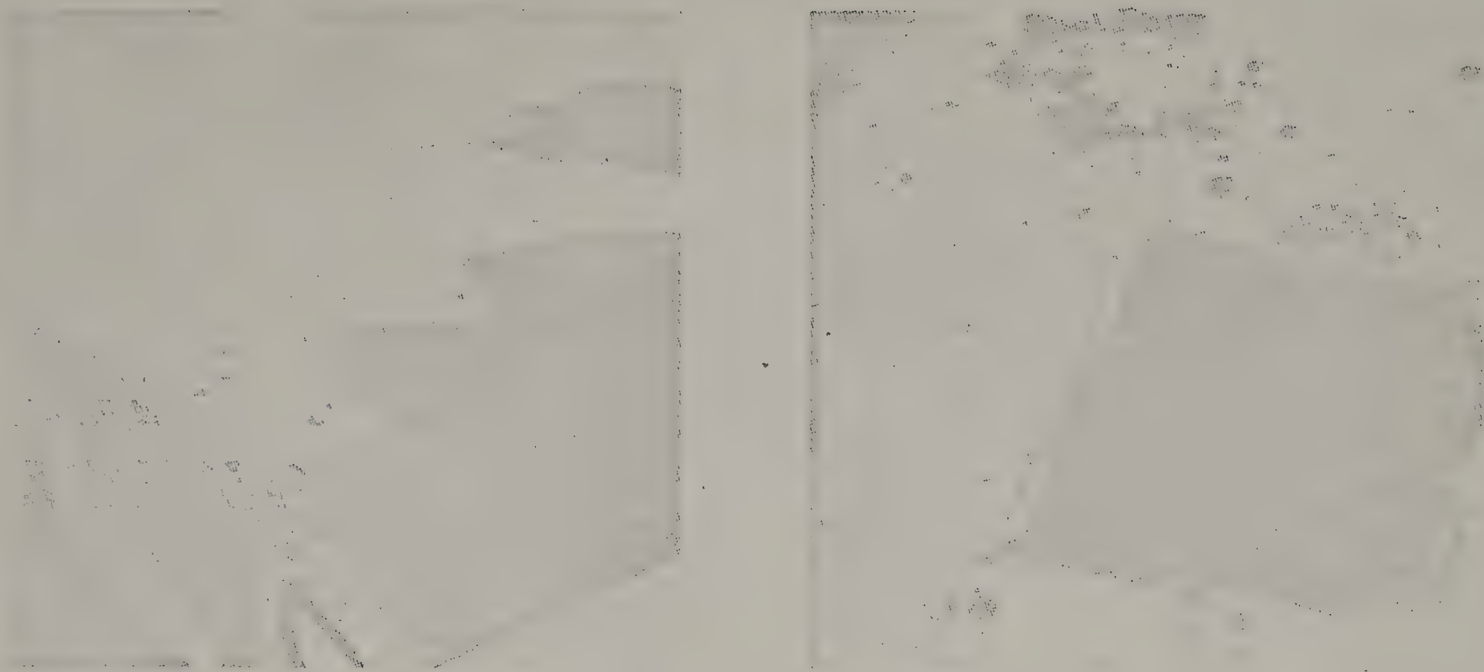


Figure 22. Lower portion of bituminous concrete wearing surface adhered to polyester resin membrane when square was removed (left). At right, membrane is exposed (end of pencil) after sratching away remaining bonded bituminous concrete.

Bituminous epoxy "A" membranes (rigid systems), showed a variety of conditions (Fig. 23). Three of seven bridges had coatings that were well bonded to the concrete slab, while the remaining four membranes were pinholed and peeled easily from the slab. This was attributed to several factors. The bonded specimens were usually at least 1/8-inch thick. Some of the unbonded specimens were 1/16-inch thick or less and exhibited pinholing from the use of a layer too thin to cover completely the aggregate in the membrane. Usually, pinholes permit ingress of moisture to the substrate which eventually results in bond failure. In some cases, poor bond was attributed to fine sand on the underside of the coating. Apparently, the sand was used in sandblasting the concrete before the membrane was placed, and was not completely removed before the membrane was installed.

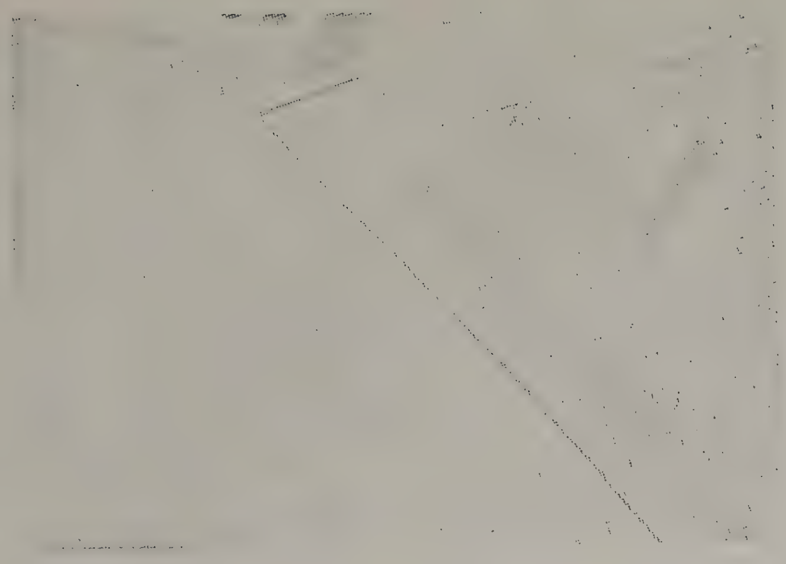
The condition of the exposed membrane coatings did not correlate in all cases with the general appearance of the structural slab underside. Where pinholing and poor bond occurred, evidence of leakage was not always detected underneath. Apparently, moisture did not infiltrate the concrete even though the coating had failed. It was also noted that water was ponded on many of these decks even though the BC wearing surface was dry. This confirmed the fact that bituminous concrete permits the ingress of moisture and ponding on the structural slab, which can eventually lead to concretre deterioration.

Prestressed Concrete Bridge

The first bridge in New York State to receive a polyester resin membrane was inspected in October, 1963, two years after placement. The purpose of the inspection was to determine the cause of water seepage observed from the underside of the deck. Five wearing course sections, which included areas of approximately 18 to 80 square feet were removed at locations coinciding with the water seepage. Four of the five areas were found to have cracks in the resin, while the remaining section was intact. Significantly, cracks in membrane coating were always found over sections where the concrete deck had cracked. One predominant location was at catch basins where cracks extended at 45° from the corner of the casting (Fig. 24a).

Inspection of the uncracked area indicated that the membrane did not provide adequate flashing at the curb joint. This emphasizes the need to continue the coating material from the deck surface to several inches above the deck along the curb face, and the importance of minimizing ponding on the structural deck. One means of accomplishing the latter is to provide drainage at the surface of the membrane.

Figure 23. Exposed Bituminized Epoxy A membrane at four locations show pinholes (upper left), pinholes and easy peeling from underlying concrete (upper right), water seepage in exposed hole with membrane peeled back (lower left), and typical appearance of membrane in good condition (lower right).



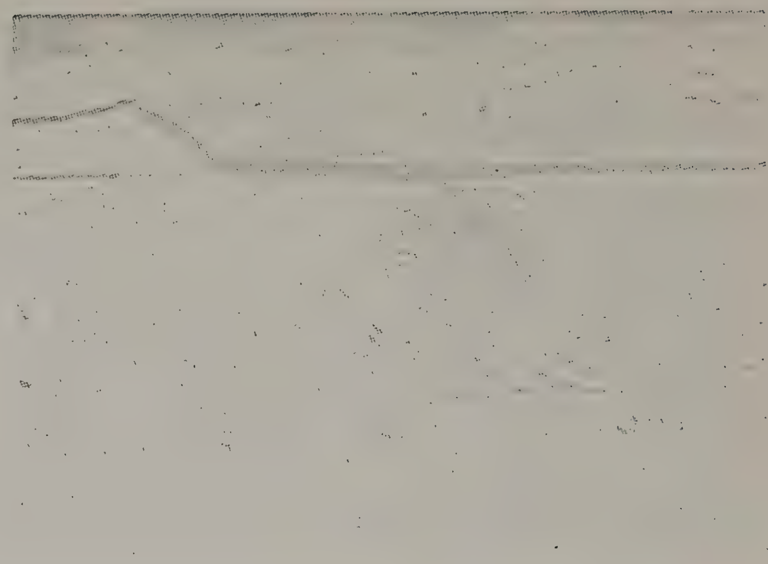
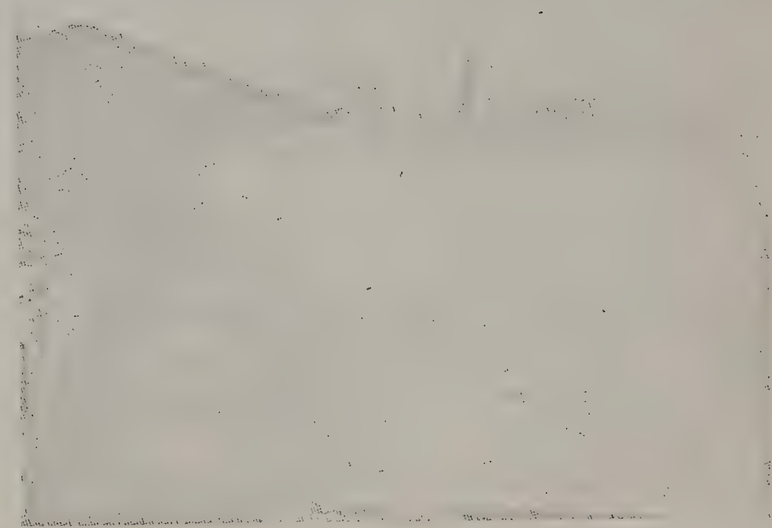


Figure 24. Defects noted on a structure with polyester resin membrane included a transverse crack in the slab extending at a 45° angle from a catch basin corner (upper left, with membrane cut away), poor membrane bond demonstrated with penknife (upper right), and ponding of water at a curb (lower right).



The integrity of the resin-to-concrete bond was determined by lightly tapping the coating with a ball-peen hammer. Poorly bonded areas had a hollow sound while the well-bonded sections sounded solid. When the poorly bonded coating was removed, the blade of a pocket knife could be inserted easily into the opening (Fig. 24b). In some cases, the resin was removed with a spade or shovel, while the well bonded areas required considerable effort with chipping hammers. The lack of bond cannot be explained, particularly when the same materials, surface preparation and construction methods were used throughout.

Evidence of bleeding or exudation, which has only been observed with polyester resin coatings, was present on this bridge deck. Of particular interest was the fact that bubbling was not apparent until late in the morning after the sun had been shining for several hours and the ambient air temperature had increased appreciably. A composite sample of the fluid was taken at several locations and chemically analyzed. The results showed that the fluid was alkaline and contained sodium and calcium chloride salts. No carbonates or iron were present. This condition is believed to result from a reaction between the alkalies in the portland cement and the polyester resin.

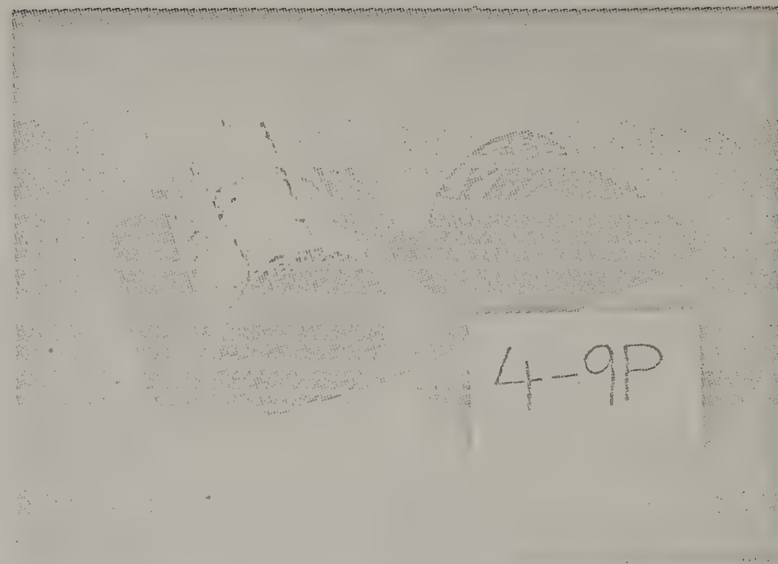
Box Beam Concrete Bridges

The underside surveys of bridges with contract-specified polyester resin membranes had indicated that in '63, 68% of the structures exhibiting leakage were of precast box-beam concrete design. As a result, six structures of this type with various degrees of seepage were carefully examined. Typically, the structural deck consists of reinforced concrete box beams butted together and tied transversely at third points with a one-inch diameter steel bar. A concrete shear key placed longitudinally between beam joints after the beams are positioned is intended to prevent differential vertical displacement. The top surface of the beams is covered with a polyester resin membrane topped with a 2 1/2 inch bituminous concrete wearing course.

During examination of structures, differential movements from 3/32 to 7/32 inch were measured between adjacent beams as normal traffic passed over the bridges. Moreover, the magnitude of movement correlated with the degree of leakage noted, on a relative basis. That is, structures with the least movement had the least leakage, and vice versa. Accordingly, several cores were removed at the keyway sections on two bridges that had the greatest movement. Figure 25 depicts two of the samples. The cores indicated that:

1. The top inch or two of the grouted keyways contained a dense, well-compacted concrete mixture; while the bottom six or seven inches was honeycombed.

Honeycombed grout and smooth surface on piece of box beam (lower right).



Well bonded polyester resin membrane with grouted keyway (left) and bituminous concrete wearing surface (right).

Figure 25. Cores extracted at keyway sections, from precast box beam bridges with polyester resin membranes.

2. The keyway grout was not bonded to the beams.

3. The polyester resin protective coating was in excellent condition and securely bonded in the majority of cored samples. Those that were not bonded were in tact and had no indication of distress.

From the examinations made, it was concluded that the polyester resin coatings were in good condition. A plausible explanation for the seepage suggested by the evidence was that water entered at the expansion joints and traveled longitudinally along the keyways, seeping out between beams where the keyway had loosened from differential deflection. This would explain the appreciable seepage noted on the sturctures where displacements were maximum, and the absence of seepage on structures where little relative movement was detected.

Experimental Coatings

Over the past several years, a variety of experimental protective coatings have been applied on the wearing surface of concrete bridge decks in New York. Except for three installations of linseed oil surface sealant on new concrete, the coatings were surface overlays applied to bridges in service 5 years or longer. The test structures were selected in the vicinity of Albany to facilitate inspection, the majority being located on Interstate Route 87. Generally, application was limited to one lane or a portion of one lane to allow comparison with uncoated areas subjected to the same traffic. Most coatings were placed only on one bridge, sometimes with other coatings in different lanes.

Table X lists the experimental materials and presents pertinent information on composition, surface preparation, application and curing, thickness and size of test area, and performance. In all cases, the surface preparation and material application was performed by the supplier in accordance with the requirements of his product. Coating performance was judged by the visual procedure described previously, namely, by its appearance and the condition of the deck underside as evidenced by leaks and efflorescense.

Periodic inspections established that all surface overlays investigated developed appreciable distress within about 2 to 3 years after application. These findings were basically in agreement with the performance of the contract-specified surface overlays previously discussed. The flexible polyester resin without fiberglas and the epoxy polysulfide were intact when inspected 9 months after installation and, therefore,

TABLE X

SUMMARY OF EXPERIMENTAL SURFACE COATINGS

Coating	Constituents	Surface Preparation	Method of Application	Coating Thickness or Coverage	Cure Time	Test Section	Remarks
Linseed Oil	50% Boiled Linseed Oil 50% Mineral Spirits	Brushed Clean	Sprayed with garden type sprayer.	Two coats, 0.025 and 0.015 gals./sq.yd.	Approx. 2-3 hrs. at 70°F. Mainly dependent upon ambient temperature	Bridge sidewalks, curbs, malls, highway pavements Approx. 4000 sq. ft.	No discernable difference between coated and uncoated air-entrained concrete after 3 years service.
Neoprene-Hypalon Rubber	Neoprene and Hypalon synthetic rubbers, #10 to #40 mesh flint grit and 1/64-inch diameter continuous strand of fiberglas	Brushed clean, used solvent and scraper on bituminous materials, normally sandblasted.	Six coats of Neoprene and one final coat of Hypalon. Last three coats contained grit, which was broadcast by hand. The fourth coat contained a continuous strand of fiberglas placed by pneumatic methods before coat was dry. All coats were placed with a paint roller, but can be brushed, rolled or sprayed.	Approximately 1/8-inch thick.	Approx. 1 to 2 hrs. between coats required for solvent release at 70°F. One week cure before traffic was permitted.	14' X 18' section of passing lane on bridge deck.	Bubbles developed after one week installation, due to insufficient release of solvents. Bond failure started at bubble after 9 months service and progressed throughout patch. Approximately 4 percent of coating removed by traffic after 2 yrs. and [illegible] coating loss after 3 [illegible].
Silicone Rubber	Silicone and sand aggregate (99% quartz) premixed in proportions of 1 part polymer to 1 1/2 parts sand.	Brushed and solvent cleaned	Mixture premixed with an electric stirrer in 5 gal. pails, poured on concrete and hand trowelled in place. A primer coat was used before coating application.	Approx. 1/8-inch thick. Used 1 gal. primer per 55 sq. ft. and 1 gal. coating per 12 sq. ft.	Prime coat cured in approx. 1/2 hr. after placing. Coating cured overnight	14'X16' section of passing lane on bridge deck	Generally in good condition for 2 yrs. after which it rapidly deteriorated. Practically removed after 3 yrs.
"	"	"	Same as above except first coat was squeegeed and second coat was hand trowelled	"	"	Driving lane on bridge deck, 1982 sq. ft.	Deterioration started by pinholing within one week. Approx. 50% removal by traffic after 5 months. Poor bond attributed to inadequate surf. preparation
"	"	Sandblasted and Vacuumed	Two coats, 1 coat squeegeed place and 2nd. coat hand trowelled.	"	"	Recoated same 1982 sq. ft. section noted above	Slight deterioration after 1 month. Practically no material remaining after 1 yr. due to traffic wear
Polyester Resin w/o fiberglas	Polyester Resin with catalyst. #12 to #30 mesh sand	Deteriorated concrete removed with jack hammer. Good concrete sandblasted and blown with compressed air. Holes patched with a polyester - aggregate grout mixture.	Prime coat of polyester resin with catalyst applied with squeegees. After 1 hr. cure time, final coat of similar materials applied in same manner. After each coat, a #30 sand broadcast by nozzle and by hand before resin cured.	Primer coat approximately 1 gal. per 98 sq.ft. Final coat approximately 1 gal per 20 sq. ft. Approx. 3/8-inch thick	Approx. 1 to 2 hrs. after placement at 50°F	2160 sq. ft. in bridge driving lane	Good condition for 14 months service after which slight deterioration noted. Approximately 40% loss of coating after 2 years

TABLE X (continued)

Coating	Constituents	Surface Preparation	Method of Application	Coating Thickness or Coverage	Cure Time	Test Section	Remarks
Polyester Resin (flexible system) w/o fiberglas	Polyester Resin with catalyst, #7 flint quartz sand, 10-20 mesh	Sandblasted and blown	Resinous components mixed in pails with power drill. Mixture poured over pavement and spread with squeegees, sand broadcast manually	Approx. 1/4" thick	Primer gelled in 30 to 40 minutes at 62° F. One hour between coats. Traffic permitted after one hour cure time	Three test sections totaling 1362 sq.ft. applied on passing lane of bridge deck. One section consisted of a polyester primer coat and two top coats, a second section contained an epoxy primer and one polyester top coat; the third section consisted of an epoxy primer with two polyester coats.	Inspection in July 1968 indicated coating starting to delaminate in section with epoxy primer and two polyester coats after 9 months service. Other test sections were in good condition.
Polyurethane	Polyurethane, two component system, with sand	Spalled concrete repaired with an epoxy resin adhesive prior to surface clearing. Half test section sandblasted, blown and broomed. Other half section had no preparation except for removal of a paint stripe.	A prime coat was applied with paint rollers and permitted to dry. The two component coating was preheated at 250°F prior to nozzle mixing during application at a nozzle pressure of 110 psi. Sand was hand broadcast before coating cured.	Approx. 3/16-inch thick	Permitted to cure for 13 hrs. after application, before opening to traffic....	2160 sq. ft. in driving lane of bridge deck	Deterioration noted after 6 weeks service, 20% coating loss after 3 months and 65% loss after 2 years.
Stabilized Rubber Vinyl Pitch	Coal tar pitch primer, stabilized rubber vinyl mixed with sand.	Brushed and blown, spots of asphalt removed by hand scraper.	A coal tar pitch primer was applied with a hand sprayer and opened to traffic after one hour. cure time. The coating was premixed mechanically and spread on concrete with squeegees in two coats.	Approx. 3/16-inch thick	Prime coat cured in one hour; the first coat took 3 hrs. drying time; the second coat was given 24hrs. drying time because of rain.	2442 sq. ft. in driving lane of bridge deck	Bond failure noted in coating after 3 weeks. Approximately 90% removed by traffic after 6 months. Poor bond was attributed to low temperatures (45°F) during placement of primer.
Epoxy Polysulfide	Two component epoxy polysulfide system with sand added to surface after application.	Hand scraped excess asphalt joint material, sandblasted and blown.	Primer coat containing 50% solids & 50% solvent was applied with mohair paint rollers. The two coating components were mixed in equal parts and spread with hand rollers and squeegee. Sand was broadcast by hand before resin system cured.	Approx. 1/8-inch thick	Primer coat was cured in one hour. Surface coat opened to traffic after 3 hours.	1734 sq. ft. in mall lane of bridge deck	Inspection in July '68 indicated coating in excellent condition except for slight wear in one corner after 9 months service.

TABLE X (continued)

Coating	Constituents	Surface Preparation	Method of Application	Coating Thickness or Coverage	Cure Time	Test Section	Remarks
Latex Mortar	Water dispersed latex applied to concrete mix, 3 parts sand, 1 part cement, 1/3 parts latex, w/c ratio 0.35 to 0.40	Concrete surface was washed, sandblasted and vacuumed.	Metal screeds placed at longitudinal joints and boards at transverse joints. Concrete was dampened and mortar brushed in. Later mortar was placed and struck off at min. thickness of 1/2-inch. Damp burlap placed on concrete for curing.	1/2-inch minimum thick	Setting time of portland cement concrete	Three portions of bridge decks coated as resurfacing or repair to decks	All coatings cracked shortly after placement. Complete deterioration and removal after 3 to 4 years service. Cracking of mortar apparently due to inadequate curing and development of shrinkage cracks.
Urethane Mortar	Urethane with solvent used as replacement for water in concrete mix.	Concrete surface was sandblasted and blown	Planks placed as forms and concrete bridge deck wet. Urethane mortar mixed mechanically in 1 cu. yd. batches and placed to 1/4-inch thickness. Normal concrete curing methods used.	1/4-inch minimum	Setting time of portland cement concrete	Approximately 1/2 section of bridge deck	Within 30 minutes after placing, considerable bubbling developed from rapid skin cure and failure to release solvents. Wind and hot sun caused rapid skin cure of mixture. Completely deteriorated in 2 years.

warrant further observation. Failure modes varied with the type of material, for example, the silicone rubber developed pin-holing while the latex mortar failed by cracking. No evidence of wet spots or efflorescense was noted on the deck underside while the coatings were intact. Upon removal of the distressed coatings, no difference was apparent in the condition of the exposed concrete compared to uncoated areas. Concrete with and without linseed oil protection, likewise, showed no difference after 3 years service.

Discussion of Results

Inspection surveys of bridge deck coatings indicated that performance varied according to intended application. Coatings used as surface overlays deteriorated within 3 yr after placement, because they could not withstand direct exposure to the damaging effects of traffic and weathering. Membranes, on the other hand, were covered with a wearing course and consequently protected from such direct, severe exposure. As a result, only 40 percent of membrane-coated bridges had any signs of leakage underneath the decks after 4 yr of service, this distress being attributed mainly to the box-beam shear key construction and coating application details, rather than to the materials used. Thus, it was concluded that surface overlays had questionable value because of their short life and high cost, while membranes, when applied properly, proved satisfactory for at least 4 yr.

In view of the past performance of bridge deck coatings and the types of distress noted on bridge decks, engineers must decide if:

1) A coating is needed for deck surfaces.

2) The selected coating is adequate for the intended application.

3) The use of a surface coating is economically justified.

The major types of distress noted in the 1963 and 1967 condition surveys of decks with concrete wearing surfaces were transverse and corner cracking, spalling and scaling. These types of distress were observed on two-course concrete decks, which are no longer specified for new construction. After 1963, contract plans for new bridge decks in New York State called for a 7-in. monolithic portland cement concrete slab to serve as a structural deck and wearing surface. Although the monolithic slab eliminates some of the distress problems inherent in two-course decks,

occasionally concrete distress can be expected because of unusual conditions or design problems. For example, cracking can occur when unfavorable weather conditions produce rapid drying of fresh concrete before proper curing is applied. Also, cracking at negative moment areas of continuous and cantilevered suspended spans can be expected at the deck surface where the concrete is in tension. Moreover, an unexpected shower or improper finishing of the concrete surface can reduce the intended amount of entrained air below the level required for prevention of scaling from de-icing salts. Conceivably, therefore, some means of deterring or preventing further distress from occuring in concrete bridge decks will be required in the future.

If one reviews past performance of bridge deck coatings, one finds that the majority did not remain intact or have sufficient flexibility to bridge cracks on decks. The few coatings with the required flexibility usually failed in bond to the substrate. One may conclude, then, that the coatings tried were unsuitable as a protective barrier where cracking and spalling occurred. Therefore, their use is limited to protection against scaling or other types of surface mortar deterioration. Considering the cost and limited life of these coatings, it is more logical to use such inexpensive surface treatments as linseed oil, which other investigators have indicated to be effective against scaling.

Bridge deck rehabilitation plans usually call for replacing deteriorated concrete in the original two-course deck with a reinforced concrete bonded to the old concrete, and finished to grade so that the deck slab is monolithic. In some instances, the old deck slab is repaired separately, and then topped with a 2 1/2-in bituminous concrete wearing course. Regardless of type of repair, it appears desirable to use a suitable epoxy resin bonding compound to bond the fresh concrete to old concrete so that construction is monolithic. Furthermore, the epoxy resin provides a barrier to surface water that may permeate the new concrete and cause further distress in the old concrete. Where a portland cement concrete wearing surface, such as on a monolithic slab, is specified, a linseed oil surface treatment appears to be the most logical to use for scaling. If a two-course deck is reconstructed, a membrane coating is recommended on the structural deck to prevent infiltration of ponded water. Final selection of material is a matter of economics, since the majority have demonstreted satisfactory performance after 4 yr of service (at the last inspection in 1967).

Conclusions

Results of the investigation of protective coatings for bridge decks warrant the following conclusions concerning the materials evaluated:

1. None of the surface overlays performed satisfactorily, as evidenced by significant deterioration within 2 to 3 yrs after placement.

2. The membrane materials (modified asphalt cutback NYS Item 361D, polyester resin, and a rigid bituminous epoxy system) appear to be performing well. Essentially all occurrences of leakage and efflorescence observed on the underside of decks with a membrane are attributable to the box-girder shear key construction and coating application details, rather than failure of the materials.

3. Silicone and distillate oil applications on non-air-entrained concrete decks did not improve long-term durability.

4. Limited field tests of linseed oil applied to air-entrained concrete pavements, bridge sidewalks, and back walls indicated no deterioration in either the treated or untreated areas after 4 yr of exposure. This supports the philosophy that properly air-entrained concrete is inherently durable and is not enhanced by surface sealants.

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APPENDIX

I. Typical Calculation and Test Procedure For Salt Content Determinations

II. Bridge Deck Core Data

III. Coating Surveys: 1965-1966

APPENDIX

I. Typical Calculation and Test Procedure
For Salt Content Determinations

TYPICAL CALCULATION AND TEST PROCEDURE FOR SALT CONTENT DETERMINATIONS (50-g SAMPLES)

Core	Slice (1-in. each)	Vol. appr. N/10 $AgNO_3$	Normality Factor Ml	% Cl	%NaCl
111	Top	1.6	1.007	0.011	0.019
111	Bottom	0.2	1.007	0.001	0.002
112	Top	0.7	1.007	0.005	0.008
112	Bottom	0.4	1.007	0.003	0.005
113	Top	3.7	1.007	0.026	0.044
113	Bottom	0.2	1.007	0.001	0.002
114	Top	2.2	1.007	0.016	0.026
114	Bottom	1.6	1.007	0.011	0.019

Calculations

$$\% \text{ Cl} = \frac{(\text{Ml } AgNO_3 \times \text{N.F.} \times 0.003546 \times 100}{\text{Grams of sample}}$$

$$= \frac{(\text{Ml } AgNO_3 \times 1.007 \times 0.003546 \times 100}{50.0} = 0.00714 \ (\text{Ml } AgNO3)$$

$$\% \text{ NaCl} = \frac{\text{Ml } AgNO_3 \times \text{N.F.} \times 0.005846 \times 100}{\text{Grams of sample}}$$

$$= \frac{\text{Ml } AgNO_3 \times 1.007 \times 0.005846 \times 100}{50.0} = 0.01178 \ (\text{Ml } AgNO3)$$

Weigh out 50 $\pm$ 0.1 g of sample on centigram balance, transfer to 600-ml beaker. Half-fill with hot water, stir, digest on steam bath, covered, about 1/2 hour, stirring occasionally. Filter hot through 9-cm. No. 40 paper in Buechner. Wash 5 times with small portions of hot water. Discard residue.

Transfer filtrate to 800-ml beaker, and evaporate on hot plate to about 50 ml. (Some $CaCO_3$ and $CaSO_4$ will crystallize out, adhering to glass, do no harm.)

Cool to room temperature. Add 2 drops of methyl orange indicator (0.1% in water). Then drip in HNO_3, stirring, until permanently acid (pink color) persisting under strong stirring.

Add $NaHCO_3$ portionwise, stirring, just enough to turn indicator back to full yellow. Then add 1 ml of 5% K_2CrO_4 and titrate to reddish end-point (persisting Ag_2CrO_4) with standard, appr. N/10 $AgNO_3$.

APPENDIX

II. Bridge Deck Core Data

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface: Type	Thick	Depth to Steel	Sod. Chlor. Cont. (%)	Air Cont. (%)	Structural Slab: Concrete Cover	Sod. Chlor. Cont. (%)	Air Cont. (%)	Remarks
1-6	CIB	Simple 4 Spans	1962	3/64	1-6-1	3	A					1 1/8	.167 .077 .016		Moderate rusting and scaling on re-steel of core 1-6-1. Core 1-6-1 extracted from low area of bridge. Inspection of underside indicated a light condition of efflorescence, cracking and moist spots
					1-6-2	3	A					3 1/4		5.0	
1-7	CIB	Simple 4 Spans	1960	3/64	1-7-1	18	C	2 7/8	1/2		1.2			7.4	Core 1-7-1 extracted from scaled area. Other cores removed from good areas. Good bond between wearing surface and slab noted on all cores. Condition survey of wearing surface indicated light flecking, light transverse cracking, severe scaling and spalling. Underside indicated light efflorescence, cracking and moist spots.
					1-7-2	8	C	3 5/8	2 3/8						
					1-7-4	7	C	3 1/2	1 1/4	.356 .019 .014	5.2		- .009 .009		
1-8	CIB	Simple 3 Spans	1959	4/64	1-8-1	9	A							4.9	Cores 1-8-2 and 1-8-3 extracted over cracks in slab. Noted 1/4-1/2" space between wearing surface and slab at core 1-8-2. Underside inspection indicated moderate efflorescence and light cracking.
					1-8-2	14	A					Broken			
					1-8-3	8	A					1 5/8		5.3	
1-13	AIB	Simple 4 Spans	1954	4/64	1-13-1	5	C	4 7/8		0.014 0.009 0.009		5/8	- 0.007 0.007		Good bond between wearing surface and slab on all cores. Light rust on steel and concrete of core 1-13-1. Light cracking on surface, light efflorescence and cracking on underside.
					1-13-2	5	C	4 1/2	3 3/4		4.6	1 1/2		5.6	
					1-13-3	8	C	4 7/8	3 3/8						
1-18	Plate Girder	Cont. 2 Spans	1955	4/64	1-18-1	3	C	3 3/8			1.9			4.2	All cores had a space of 1/8-1/4" between wearing surface and slab. Cores 1-18-1 and 1-18-3 removed from moist areas. Light rust on re-steel and concrete of core 1-18-3. Inspection of topside indicated light popouts and scaling, moderate spalling and cracking. The underside indicated severe efflorescence and cracking.
					1-18-2	5	C	3 3/8	2 3/8		2.1			2.5	
					1-18-3	7	C	3 3/8	2 3/8	0.234 - -		1 1/4	- 0.068 0.016		
1-23	Conc. Slab Simple Span	1 Span	1957	4/64	1-23-1	3	A							3.1	All cores in good condition. Structure was in excellent condition.
					1-23-2	7	A						0.070 0.047 0.009		
1-35	Arch Susp.	3 Simple Span on Each end of arch susp.	1959	4/64	1-35-1	7	C	4 5/8	3 1/2	0.234 0.009 0.006		4 1/2	0.007 0.007 0.014		Space of 1/8-1/4" between wearing surface and slab of all cores. Core 1-35-1 drilled to top of SIP metal forms. Cores 1-35-1 and 1-35-2 taken at cracked areas. Severe rust on re-steel and concrete of core 1-35-1. Core 1-35-2 cracked completely through wearing surface. Linear traverse results of top 1-inch of core 1-35-3 indicated 9.66% total air and 8.05% entrained air content. Inspection of wearing surface indicated light scaling, severe spalling and cracking. Stay-in-place metal forms exclude visual survey underneath.
					1-35-2	6	C	4 5/8	2 7/8	0.297 0.051 0.044		2	0.054 0.021 -		
					1-35-3	7	C	4 1/8			8.5	1 1/2		3.2	

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface: Type	Wearing Surface: Thick	Wearing Surface: Depth to Steel	Wearing Surface: Sod. Chlor. Cont.(%)	Wearing Surface: Air Cont. (%)	Structural Slab: Concrete Cover	Structural Slab: Sod. Chlor. Cont.(%)	Structural Slab: Air Cont. (%)	Remarks
1-36	CIB	Simple 3-span	1949	4/64	1-36-1	15	C	4 3/8	2 1/2	-	3.8			2.4	The topside indicated moderate popouts, light scaling and cracking. Light moist spots noted underneath.
					1-36-2	18	C	5 1/2	2 1/2	.260 .103 .129		1 1/8	0.034 0.049 0.037		
					1-36-3	16	C	4 3/8	2 5/8	.470 - .010			0.110 0.050 0.030		
2-1	CIB	Simple	1937	4/64	2-1-1	7	C	4 3/4	3 1/4	.096 .016 .033		1 1/8			Two of four cores had a space 1/8-1/4" between wearing surface and structural deck, while the remaining two were well bonded. All cores extracted from moist areas, yet concrete is in good condition. Core 2-1-2 extracted in cracked area. Light scaling and spalling, moderate flecking, popouts and cracking on wearing surface. The underside indicated severe efflorescence and cracking.
		3 Span			2-1-2	16	C	4	3 1/8	.162 .016 .007		2 1/4	.021 .012		
					2-1-3	6	C	3 7/8	2 5/8		6.6	1 5/8		1.6	
					2-1-4	6	C	5	4 1/8		3.6				
2-15	Plate Girder	Cant. Susp. 4 span 1 suspended 2 anchor 1 simple	1956	4/64	2-15-1	6	C	4 3/8	3 1/4	.037	6.3	1 3/8	.010	1.3	Core 2-15-1 extracted in good area Core 2-15-2 cored over crack. Light rust on re-steel and concrete. Core 2-15-3 extracted over moist spot. All three cores had 1/8-1/4" space between wearing surface and slab. Inspection of wearing surface showed evidence of severe cracking and moderate popouts. Underside had severe efflorescence and cracking.
					2-15-2	4	C	4	3 1/8	.040 -	-	2 1/8	.010 .040		
					2-15-3	4	C	5	3 5/8		7.7				
2-17	CWFB	Simple 3 Span	1960	4/64	2-17-1	2	A	-	-	-	-		.126 .061 .009	-	All cores in good condition. Underside was in good condition.
					2-17-2	10	A	-	-	-	-	1 1/8		3.4	
2-20	PCB	Simple 1 Span	1958	4/64	2-20-1	7	C	4	2 1/4		4.2	-	-	-	All cores in good condition. Light flecking on surface. Light efflorescence on underside.
					2-20-2	3	C	3 5/8	2 1/4						
3-4	CIB	Simple	1958	4/64	3-4-1	18	C	4 1/4	3 3/8	.705 .066 -					All four cores show good bond between wearing surface and slab. All cores in good condition. Core 3-4-1 extracted in scaled area. Core 3-4-1 had light corrosion on re-steel. Deck has been resurfaced with asphaltic concrete. Scaling on concrete visible in isolated areas.
		4 Span			3-4-2	18	C	3 3/4	2 3/4		3.0	2 3/8		4.2	
					3-4-3	7	C	3	1	.345 .136 .073		2 1/4	.096 .059 .014		
					3-4-4	1	C	4 1/2	1 5/8		4.9	3 1/8		5.1	

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface: Type	Thick	Depth to Steel	Sod. Chlor. Cont. (%)	Air Cont. (%)	Structural Slab: Concrete Cover	Sod. Chlor. Cont.(%)	Air Cont. (%)	Remarks
3-7	CIB	2 Simple	1959	4/64	3-7-1	6	A					1			Cores 3-7-1 and 3-7-2 were in good condition Core 3-7-2 was porous. Structure in good condition.
		2 Cont.			3-7-2	6	A					1 3/8	.014 .009 -		
		4 Spans			3-7-3	7	A					3/4	.023 .016 -		
3-8	AIB	Simple	1953	4/64	3-8-1	7	C	4 1/2		.690 .100 .070		1	.060 .047 -		All cores except 3-8-3 were in good condition. Space of 1/8-1/4" between wearing surface and slab on all cores. Core 3-8-1 had light rusting on re-steel and concrete. Cored 3-8-2 sample over moist area. Moderate cracking and asphalt patches observed on wearing surface. Moderate efflorescence and light cracking noted underneath.
		4 Spans			3-8-2	4	C	5	4 1/8						
					3-8-3	3	Rubble								
					3-8-4	3	C	3 1/2	3 1/4		4.0	1 7/8			
4-1	AIB	Simple 4 Span	1955	4/64	4-1-1	4	C	3 3/4	2 5/8		4.4	1 1/8		3.0	Spacing 1/8"-1/4" between wearing surface and slot on all three cores. All cores were in good condition. Cores 4-1-1 and 4-1-3 taken over wet spots. Core 4-1-2 extracted at scaled area. Light scaling, spalling and cracking noted on wearing surface. No distress observed underneath.
					4-1-2	15	C	4 1/8	3/4		4.7	1 1/8		2.8	
					4-1-3	4	C	4	2 3/4	.407 .199 .171		1 1/2	.108 .028 .020		
4-19	CIB	Contin. 3 Span also Susp. Panels	1961	5/64	4-19-1	5	A					1	.115 .049 .012		All cores in good condition - Bituminous waterproofing between courses. Moderate efflorescence and cracking noted underneath.
					4-19-2	5	A							3.7	
					4-19-3	5	A						.126 .007 .002		
4-25	CIB	Simple 4 Span	1958	5/64	4-25-1	6	A					1 5/8	.145 .112 .016		All cores in good condition. Core 4-25-1 extracted over wet spot. Severe efflorescence and light cracking observed underneath.
					4-25-2	6	A					1 7/8		2.9	
					4-25-3	6	A					1 1/8		2.9	
4-35	AIB	Simple & Cantil. Sp. 15 Spans	1954	5/64	4-35-1	7	A					7/8		2.5	All cores in good condition. Core 4-35-4 extracted in patched area. Newly patched area at core 4-35-2. Weary course resurfaced with asphaltic concrete in good condition. Underside shows evidence of moderate efflorescence and moist spots with light cracking.
					4-35-2	7	A					1 5/8		6.7	
					4-35-3	4	A					1 1/8	.297 .061 .047		
					4-35-4	6	A					1 7/8	.371 .344 .023		

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface Type	Wearing Surface Thick	Wearing Surface Depth to Steel	Wearing Surface Sod. Chlor. Cont. (%)	Wearing Surface Air Cont. (%)	Structural Slab Concrete Cover	Structural Slab Sod. Chlor. Cont. (%)	Structural Slab Air Cont. (%)	Remarks
5-3	Plate Girder	Simple 2 Spans	1963	5/64	5-3-1	2	A							2.9	All cores in good condition. Polyester resin protective coating membrane between wearing surface and slab. S.I.P. steel forms underneath slab. Concrete expansion headers show moderate spalling. Stay-in-place metal forms prevented observation of deck underside.
					5-3-2	9	A					1 5/8	.016 .009 .012		
					5-3-3	9	A						.012 .015 .020		
5-5	AIB	Simple 3 Span	1956	5/64	5-5-1	12	C	3 3/4	2 1/8	.259 .049 .054		7/8	.047 .026 .021		Core 5-5-1 extracted in area with deteriorated wearing surface. Slab is in good condition and shows evidence of light rusting on re-steel and concrete. Core 5-5-2 extracted in area with transverse cracks. Light rust is evident on re-steel. Core 5-5-3 removed from patched area. All cores have porous aggregate and show 1/8-1/4" space between wearing surface and slab. Severe scaling and cracking on wearing surface. Underside in good condition.
					5-5-2	14	C	4 1/4	3	.263 .073 .045		1 3/8	.014 .014 -		
					5-5-3	5	C	3 1/2	2 1/2		6.6	1 3/8		4.3	
5-10	AIB	Simple 1 Span	1956	5/64	5-10-1	12	C	4 1/2	2 7/8		7.2	1 3/8		9.7	Both cores have good bond between wearing surface and slab. Core 5-10-1 in good condition. Core 5-10-2 porous with light rust on re-steel. Deck resurfaced with asphaltic concrete. Underside showed light moist spots.
					5-10-2	12	C	4 7/8	3 7/8	.491 .007 .047		1 1/4	.023 .047 .023		
5-13	AIB	Cantil. Susp. and Simple 7 Spans	1957	5/64	5-13-1	3	C	3 7/8	3 1/4	.402 .061 .007		2.0	.005 .008 .007		Four cores with 1/4-1/2" space between wearing surface and slab. One core well bonded between courses. Core 5-13-1 extracted from wet area with efflorescence. Sample in good condition but shows light rusting on steel and concrete. Core 5-13-2 removed from badly cracked and patched area. Core 5-13-3 was rubble and core 5-13-5 could not be removed. Sample 5-13-4, in good condition, was removed from good area. Light flecking, scaling, spalling, and severe cracking on wearing surface. Light efflorescence and cracking underneath.
					5-13-2	3	C	3 1/4	3	.367 .211 .187					
					5-13-3	2	C	3 7/8	2		6.0	Rubble			
					5-13-4	4	C	3 5/8	3		5.9	2.0		2.8	
					5-13-5	2	C	3 1/2	3 3/8		5.1				
5-16	AIB	Simple 2 Span	1955	5/64	5-16-1	6	C	4 3/8	3 3/8		7.9	1 5/8			All cores contained porous aggregate. Noted 1/2-1/4" spacing between wearing surface and slab on all cores. Core 5-16-1 taken in cracked area. Core 5-16-3 in good condition. Bituminous waterproofer between courses. Light flecking, moderate scaling and spalling and severe cracking on wearing surface. Underside indicated moderate efflorescence, moist spots and cracking.
					5-16-2	18	C	4 1/2	2 7/8	.435 .159 .077			- .060 -		
					5-16-3	18	C	4 5/8	3 1/4	.255 .066 .056		1 5/8	.042 .063 -		

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface Type	Wearing Surface Thick	Wearing Surface Depth to Steel	Wearing Surface Sod. Chlor. Cont.(%)	Wearing Surface Air Cont. (%)	Structural Slab Concrete Cover	Structural Slab Sod. Chlor. Cont.(%)	Structural Slab Air Cont. (%)	Remarks
5-17	AIB	Simple 3 Span	1955	5/64	5-17-1	3	C	3 7/8			12.5	2			Both cores contained porous aggregate and in good condition. Good bond between concrete courses. Moderate cracking on wearing surface. Underside in good condition.
					5-17-2	20	C	4 1/4	2 3/4	.601 .056 .056		1 3/8	.028 .056 .068		
5-28	CWFB	Cont. 3 Span	1963	5/64	5-28-1	6	C	4	2 7/8		5.9				All cores showed good bond between concrete courses. Cores in good condition. Wearing surface has shrinkage cracks. Slab in good condition. Inspection of wearing course indicated severe cracking. Light efflorescence underneath.
					5-28-2	4	C	4 1/4	3 1/4	.180 .030 .020		1 7/8	.030 .020 -		
					5-28-3	2	C	4 1/4	3 1/2		5.3			3.8	
					5-28-4	2	C	4 5/8		.194 .030 .026			.021 .014 -		
5-34	AIB	Cont. 2 Span	1952	5/64	5-34-1	5	A					2 7/8	.023 .023 .021		Cores in good condition. Cored areas showed evidence of leakage on slab. Silicone water-proofer between courses. No distress noted.
					5-34-2	5	A							1.8	
6-1	Comp. Deck Girder	Simple 10 Span	1959	4/64	6-1-1	3	C	3 3/8	2 1/8		8.6			2.7	All cores showed good bond between wearing surface and slab. Cores 6-1-1 and 6-1-2 in good condition. Core 6-1-2 extracted over cracked area. Core 6-1-3 removed in area where pavement was cracked and patched. Sample was porous and showed light rust on re-steel. Core 6-1-4 disintegrated below resteel. Evidence of light rusting on re-steel and concrete of sample. Light scaling and spalling, moderate cracking on surface. Moderate cracking and efflorescence under-neath.
					6-1-2	6	C	3 5/8	2		6.5	1 3/8			
					6-1-3	6	C	3 5/8	2	.253 .033 .063		1 1/8	.042 .037 .026		
					6-1-4	10	C	4 3/8	2 7/8	.022 .012 .010		1 3/8	.010 .010 .007		
6-2	AIB	Simple 4 Span	1956	4/64	6-2-1	3	C	4 1/4	3		4.7	2 1/8		3.6	Noted 1/8-1/4" space between wearing course and slab on both cores. Light rust on re-steel and concrete of sample 6-2-2. Both cores in good condition. Moderate cracking on wearing surface. Severe efflorescence and cracking with light moist spots under-neath.
					6-2-2	3	C	3 1/2	3 1/8	.363 .045 .170		2 1/8	- .110 -		
6-3	AIB	Cantil. Susp 3 Span	1956	4/64	6-3-1	18	C	4	2 3/4	.103 .035 -		1 7/8	.021 .042 .014		Noted 1/8-1/4" space between courses on two samples. One core shows good bond between courses. Wearing surface broken and patched on sample 6-3-3, which was in good condition. Other samples in poor condition. Severe cracking on deck surface. Severe efflorescence and cracking underneath.
					6-3-2	20	C	4	3 3/4						
					6-3-3	20	C	4	3 1/8		4.0	1 1/8		4.4	

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface: Type	Wearing Surface: Thick	Wearing Surface: Depth to Steel	Wearing Surface: Sod. Chlor. Cont.(%)	Wearing Surface: Air Cont. (%)	Structural Slab: Concrete Cover	Structural Slab: Sod. Chlor. Cont.(%)	Structural Slab: Air Cont. (%)	Remarks
7-31	CIB	Simple 3 Span	1959	4/64	7-31-1	7	A					1 1/8			All cores in good condition. Light rust on steel and concrete of core 7-31-3. No condition survey permissible underneath due to stay-in-place metal forms.
					7-31-2	9	A						.016 .007 .010		
					7-31-3	9	A					2 1/4	.014 .009 .014		
7-35	CIB	Simple 5 Span	1959	4/64	1-35-1	5	A					1 1/8		2.8	Cores 7-35-1 and 7-35-3 in good condition. Sample 7-35-2 porous. No condition survey permissible underneath due to stay-in-place metal forms.
					1-35-2	5	A					7/8	.007 .005 -		
					1-35-3	5	A					7/8	.008 .009 .009		
8-2	CIB	Cantil. Susp 2 Anchor 1 Susp.	1960	4/64	8-2-1	7	C	4 1/2	3 3/4			1 1/2		1.6	Cores 8-2-1, 2, and 4 in good condition. Core 8-2-3 broken at surface. Corrosion of re-steel noted on core 8-2-2. All cores showed evidence of 1/8-1/4" space between courses. Bituminous waterproofer between two courses. Severe to moderate cracking on deck surface. Light moist spots and moderate efflorescence noted underneath.
					8-2-2	9	C	4 1/8	2 7/8	.082 .012 .009		3/4	.009 .009 .009		
					8-2-3	9	C	4 1/2	3 3/8	.154 .007 .005			.007 .006 -		
					8-2-4	9	C	3 7/8	2 7/8		2.2			1.4	
8-5	PCB	Simple 3 Span	1959	4/64	8-5-1	6	C	3 3/8	3 1/8		4.7				Core 8-5-1 extracted in deteriorated area. Cores 8-5-2 and 3 removed in checked area. Light spalling, severe to moderate cracking on surface. Underside in good condition.
					8-5-2	6	C	4 1/8	3 5/8		5.5				
					8-5-3	6	C	3 1/4	2 3/4						
8-6	AIB	Simple 6 Span	1954	4/64	8-6-1	8	C	3 3/8	3 1/4	.098 .051 .045		2	- .019 -		All cores showed evidence of 1/4-1/2" spacing between two courses. All cores in good condition. Core 8-6-2 showed light rusting on resteel and concrete. Moderate scaling, severe spalling and cracking on deck surface. Light efflorescence underneath.
					8-6-2	9	C	3 1/8	1						
					8-6-3	9	C	4 1/8	4		2.3				
					8-6-4	2	C	2 5/8	2 1/2					1.6	
9-4	CIB	Simple 3 Span	1960	4/64	9-4-1	6	C	4 1/8	1 1/2	.124 .002 .002		2 3/4			All cores showed good bond between wearing course and slab. Core 9-4-1 removed from popout area. Underside in good condition. Core indicated light rust on resteel. Core 9-4-2 extracted from pothole area. Underside in good condition. Core 9-4-3 removed from good area. Light rust on resteel. Extracted core 9-4-4 from area with map cracking. Severe flecking, popouts and cracking, moderate scaling and spalling on wearing surface. Underside was in good condition.
					9-4-2	2	C	3 7/8	3 5/8		2.6			1.7	
					9-4-3	7	C	4	3 3/4	.190 .005 .005		1 1/8			
					9-4-4	8	C	4 3/8	3 7/8		2.5	1 3/8		2.5	

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface Type	Wearing Surface Thick	Wearing Surface Depth to Steel	Wearing Surface Sod. Chlor. Cont.(%)	Wearing Surface Air Cont. (%)	Structural Slab Concrete Cover	Structural Slab Sod. Chlor. Cont.(%)	Structural Slab Air Cont. (%)	Remarks
9-10	CIB	Simple	1960	4/64	9-10-1	10	C	4 5/8	4 3/8	.034 .004 .006		7/8	.015 .005 -		Both cores indicated good bonding between two courses of concrete deck. Core 9-10-1 extracted from good area and indicated light rusting of re-steel. Core 9-10-2 removed from cracked area. Severe flecking and cracking, light popouts and scaling, and moderate spalling on wearing surface. Light efflorescence and moist spots underneath.
		3-Span			9-10-2	15	C	4 1/4	3 1/8		2.4			2.6	
9-12	Deck Girder	Cantil. Susp. 3 Span	1954	4/64	9-12-1	7	Rubble					Rubble	- .015 .005		Cores 9-12-1 and 9-12-2 extracted in areas with concrete deterioration. Both cores disintegrated during removal. Cores 9-12-3, 9-12-4 and 9-12-5 removed from areas which appeared to be in good condition. However, all cores broke in pieces. Inspection during core removals indicated a spacing of 1/8-1/4" between concrete courses on all cores. Light flecking and cracking on wearing surface. Severe efflorescence, light cracking and moist spots underneath.
					9-12-2	10	Rubble					Rubble			
					9-12-3	8	C	2 3/4	1 1/8			2 1/8		1.9	
					9-12-4	8	C	2 3/4	2 1/2			1 7/8			
					9-12-5	6	Rubble					2 1/4			
9-17	CIB	Simple 4 Span	1960	4/64	9-17-1	16	C	3 3/4	2 3/8		2.3	1 1/2		2.6	Entire structure has map cracking. Core 9-17-3 indicated light rusting on resteel. All cores in good condition, except that slab section of 9-17-2 was porous. Two cores indicated good bond between two course deck, while one core had a 1/8-1/4" space. Linear traverse measurements of core 9-17-2 taken in longitudinal direction of wearing surface indicated total air content of 2.73% and 1.94% air entrainment. This is an air entrained structure. Severe spalling and cracking on wearing surface. Underside in good condition.
					9-17-2	16	C	3 5/8	2 3/8		2.4	1		1.3	
					9-17-3	18	C	3 1/2	2 1/4	.240 .033 .012		1 5/8	.005 .007 .007		
9-21	AIB	Simple 1 Span	1957	4/64	9-21-1	10	C	4	3 1/2	.103 .016 .012		1 5/8	.010 .014 .014		Both cores extracted in wet areas indicated good bond between courses of deck concrete. Core 9-21-1 from low side showed voids in sample and light rusting on slab steel. Core 9-21-2 from high side was in good condition. Linear traverse measurements on transverse section of core 9-21-2 wearing surface indicated total air content of 2.71 and 2.06% air entrainment. This is an air entrained structure. Severe spalling and transverse cracking on deck surface. Light efflorescence and cracking underneath.
					9-21-2	4	C	3 7/8	3 1/4		2.8	1 5/8		0.7	

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface: Type	Wearing Surface: Thick	Wearing Surface: Depth to Steel	Wearing Surface: Sod. Chlor. Cont. (%)	Wearing Surface: Air Cont. (%)	Structural Slab: Concrete Cover	Structural Slab: Sod. Chlor. Cont. (%)	Structural Slab: Air Cont. (%)	Remarks
9-24	CIB	Simple 4 Span	1959	4/64	9-24-1	12	C	3 5/8		.144 .009 .009		2 5/8	.007 .007 .007		All cores indicated good bonding between two course deck construction. Cores 9-24-1 and 9-24-3 removed from good areas. Core 9-24-2 extracted from cracked area indicated light rusting on re-steel. Moderate cracking on wearing surface. Severe efflorescence, moist spots and cracking underneath.
					9-24-2	12	C	4 3/8	3 1/2	.070 .026 .021		1 1/8	.021 - .021		
					9-24-3	12	C	3 3/8	2	.030 -	3.4	1 1/2		3.9	
9-27	AIB	Simple 1 Span	1951	4/64	9-27-1	6	C	2 1/2	1	-		1 1/2		2.4	Core 9-27-1 extracted from good area showed no defects. Core 9-27-2 removed from cracked area, indicated light rusting on re-steel and concrete. Bituminous waterproofer noted between courses. Deck resurfaced with asphaltic concrete. Underside shows light efflorescence and moderate moist spots.
					9-27-2	6	C	2 5/8	1 7/8	.022 .012 .007		1 1/4	.005 .007 .006		
10-2	Plate Girder	Cantil. Susp. 15 Span	1949	6/64	10-2-1	6	C	3 1/4	2 3/4	.137 .040 .030		3/4	.073 .068 .059		All cores indicated good bond between courses. Cores 10-2-1 and 10-2-4 extracted from good areas and both in good condition. Core 10-2-1 indicated light rust on slab reinforcement. Core 10-2-2 extracted from area with transverse cracks. Wearing surface core cracked, structural sections in good condition. Core 10-2-3, removed from area with alligator crack pattern, found in good condition. Moderate scaling, spalling, and cracking on deck surface. Moderate efflorescence, moist spots and cracking underneath.
					10-2-2	7	C	3 3/8	3 1/8	.154 .073 .039		1 1/4	.073 .060 .047		
					10-2-3	7	C	2 3/4	1 5/8		4.5	1 3/8			
					10-2-4	7	C	2 3/4	2 1/2		3.5				
10-11	CIB	Simple 4 Span	1959	6/64	10-11-1	6	C	4 3/4	2 1/8		7.1			5.5	Cores 10-11-1 and 10-11-3 removed from light scaled areas. All cores in good condition except for honeycomb in wearing surface of core 10-11-2. Cores 10-11-3 and 10-11-4 show evidence of light rust on wearing surface reinforcement. All cores indicated good bond between courses. Light cracking, spalling, scaling and moderate flecking on deck surface. Underside was in good condition.
					10-11-2	7	C	3 3/8	1		7.3	2 1/4		5.4	
					10-11-3	16	C	3 3/8	1 3/4	.234 .070 .023		2 1/4	.020 .020 -		
					10-11-4	6	C	3 5/8	2	.128 .021 .028			.012 .032 -		

CORE DATA

Bridge File No.	Design	Support	Year Built	Date Cored	Core No.	Distance From Curb (Ft.)	Wearing Surface Type	Wearing Surface Thick	Wearing Surface Depth to Steel	Wearing Surface Sod. Chlor. Cont. (%)	Wearing Surface Air Cont. (%)	Structural Slab Concrete Cover	Structural Slab Sod. Chlor. Cont. (%)	Structural Slab Air Cont. (%)	Remarks
10-25	Plate Girder & I Beam	Continuous 16 Span	1956	6/64	10-25-1	8	C	3 3/8			4.4				One core indicated good bond between courses. Remaining courses showed 1/8 - 1/4" space between courses. All cores in good condition. Core 10-25-2 indicated light rust on wearing course re-steel. Core 10-25-4 showed light rust on slab re-steel. Moderate to severe spalling and cracking on surface. Moderate efflorescence, moist spots and cracking underneath.
					10-25-2	5	C	4	3 1/8	.225 .088 .091					
					10-25-3	5	C	4 1/4			4.5	2 1/8		3.9	
					10-25-4	6	C	3 3/8	3	.313 .110 .103		1 1/8	.066 .061 -		
					10-25-5	6	C	4	3		6.0	1/4		5.0	
10-26	Composite Plate Girder	Cont. & Simple 11-SP.	1959	6/64	10-26-1	7	C	3 3/4		.210 .190 .070					All cores in good condition. Monolithic deck with light transverse cracking and scaling. Light scaling and moderate cracking on wearing surface. Light efflorescence and moderate cracking underneath.
					10-26-2	8	C	3 3/4	3 1/2	.1-0 .122	5.2				
					10-26-3	6	C	3 1/4		-					
					10-26-4	6	C	4	3 3/4		4.6				
These Cores Were Used For Control Purposes For Sodium Chloride Tests															
9-31			1963	10/63	9-31-2	11	C	4	2 3/4	.009 .009 .007					Cores were extracted before bridge was opened to traffic to represent a structure without salt.
					9-31-5	10	C	3 3/4	2 3/4	.009 .009 .009					
					9-31-6	9	C	4		.009 .005 .005					
4-36					9000		C	12		.020 .021 .020					Tests conducted on 6 x 12" concrete cylinders.
					9022		C	12		.007 .023 .019					
					9039		C	12		.016 .023 .026					

APPENDIX

III. Coating Surveys: 1965-1966

PCBB: Prestressed Concrete Box Beams
CIB: Composite I-Beam
CWFB: Composite Wide Flange Beam
PCB: Precast Concrete Beam
CIB: Precast Concrete I-Beam
CPG: Composite Plate Girder
CDBC: Concrete Double Box Culvert

BRIDGES WITH POLYESTER RESIN W/FIBERGLASS SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
1-1 N.B.	CIB	3	1965	After 2 yrs. service, pinholes with bleeding formed at surface, afterwhich cracking and deterioration occurred. Two sections were experimentally replaced in 1963. One section delaminated quickly, while the other section without fiberglas performed much better. In April 1965 practically all of coating with exception of approx. 900 sq. ft. had deteriorated and was removed. The remaining section of 900 sq. ft. was well bonded and still in tact during July 1965.	Good condition - no leaks
1-1 S.B.	CIB	3	1965	Remarks same as above.	Remarks same as above

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
1-3	PCBB	5	1965	Asphalt-Concrete in good condition	Moderate leakage between beams and over piers.
			1966	No Defects	Very slight staining at piercaps-moist-crack over one pier.
1-4A N.B.	PCBB	5	1965	Asphalt-Concrete in good condition	Heavy leakage, wet spots and efflorescence between beams.
			1966	Slight transverse cracks at span joints	Slight moisture and staining at pier caps and between beams.
1-4B S.B.	PCBB	5	1965	Asphalt-Concrete in good condition	Heavy leakage, wet spots and efflorescence between beams.
			1966	Slight transverse cracks at lane joints	Slight moisture and staining at pier caps and between beams.
1-5	CIB	5	1965	Many patches in asphalt-concrete	Efflorescence and crack under mall joint.
			1966	General moderate patching-some peeling and scaling	Efflorescence at long. center joint-cracked and efflorescence under center mall joint
1-6	PCTB	5	1965	Asphalt-Concrete in good condition	Good condition - no leaks
			1966	No Defects	No Defects
1-7A N.B.	PCBB	5	1965	Patching in driving lane	Heavy leakage between interior beams.
			1966	No Defects	Moderate staining and moisture between beams and at pier caps.
1-7B S.B.	PCBB	5	1965	Asphalt-concrete in good condition	Heavy leakage between interior beams.
			1966	No Defects	Moderate staining and moisture between beams and at pier caps.

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Asphalt - concrete cracked	Slight leakage between beams
1-8A N.B.	PCBB	5	1966	No Defects	Slight moisture and staining at pier caps
			1965	Asphalt - concrete heaved over west pier	Slight leakage between beams
1-8B S.B.	PCBB	5	1966	No Defects	Slight moisture and staining at pier caps
			1965	Asphalt - concrete in good condition	Heavy leakage between several beams
1-9	PCBB	5	1966	No Defects	Slight moisture and streaking over pier caps
			1965	Asphalt - concrete in good condition	Efflorescence and leakage between beams
1-10	PCBB	5	1966	No Defects	Slight moisture at pier caps and between beams
			1965	Asphalt - concrete in good condition	Diagonal cracks with efflorescence at corners of open grating
1-11	CWFB	5	1966	No Defects	Slight diagonal cracks near drains. Effl.
			1965	Asphalt-concrete in good condition	Diagonal cracks with efflorescence at corners of open grating
1-12	CWFB	5	1966	No Defects (some cracks at open grating)	Slight to moderate diagonal cracking near drains and slight rusting (beams, drains)
			1965	Asphalt - concrete in good condition	Diagonal cracks with efflorescence at corners of open grating
1-13	CWFB	5	1966	One diagonal crack near open drain corner	Moderate diagonal cracks and efflorescence at corners of open drains
			1965	Cracks and potholes in asphalt-concrete	Mostly inaccessible-Visible area in good condition
1-14	F.C. Arch	5	1966	Moderate transverse cracks at lane joints and general A.C. patching in traffic lanes	Moderate severe leakage at abutments and pier caps-efflorescence stalactites (1st lane

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Cracks at corners of open grating	Good Condition - Bridge opened to traffic in 1965
1-15 S.B.	CIB	5	1966	Concrete abuting joints at abutments badly broken up-steel kids show	No defects
			1965	Transverse cracks adjacent to abutment	Good Condition - No leaks
1-16	CIB	5	1966	Cracked at abutments	No defects
			1965	Evidence of bleeding through asphalt-concrete	Leakage between beams
2-1	PCBB	4	1966	Very slight bleeding stains and slight longitudinal cracking at mall joint	Moderate wetness and effl. between beams
			1965	Evidence of bleeding through asphalt-Concrete	S.I.P. Forms - good condition
3-1 E.B.	CPG	2	1966	Mod. to mod. severe cracking at span joints over piers	No defects
			1965	Asphalt-concrete in good condition-Not open to traffic	S.I.P. Forms - good condition
3-1 W.B.	CPG	2	1966	Mod. to mod. severe cracking at span joints over piers	Leakage and rust at 1 S.I.P. joint - moderate
			1965	Evidence of bleeding through asphalt-concrete	S.I.P. Forms - good condition
3-2	CIB	2	1966	Mod. transverse cracking at span joints	No defects
			1965	Asphalt-concrete in good condition	S.I.P. Forms - good condition
3-3	CIB	2	1966	Mod. transverse cracking at span joints over pier caps	No defects
			1965	Longitudinal cracks in asphalt-concrete, slight bleeding thru asphalt-concrete. Removed wearing surface for study.	Efflorescence and leakage between girders-diagonal cracks at Scuppers

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
3-4 N.B.	PCB	6	1966	Random cracking & test patches - pumping water - 1st. 2nd. lanes	(Between Beams) Mod. random effl. - Long. trans., diag. and (Between Beams) random cracking
			1965	Similar to N.B. structure except in poorer condition	Efflorescence and leakage between girders diagonal cracks at scuppers. Note special study of bridge
3-4 S.B.	PCB	6	1966	Random cracking & test patches - pumping water -1st. and. 2nd. lanes	Moderate (between beams) random efflorescence Long. trans., diag. and random cracking (between beams)
			1965	Longitudinal crack in asphalt-concrete W.B. lane	Good condition - No leaks
4-1	CIB	4	1966	Moderate severe-deep holes, long. cracks and A.C. patches-at mall joint	No Defects
			1965	Longitudinal crack in asphalt-concrete W.B. lane	Good condition - No leaks
4-2A E.B.	CIB	3	1966	Ponding - no defects	Moderate wet efflorescence and transverse cracking-between beams
			1965	Random cracking in decelerating lane	Crack with efflorescence near pipe drain
4-2B W.B.	CIB	3	1966	Ponding-slight long. and random cracking at lane joints	Moderate severe moist and transverse cracks-between beams
			1965	Asphalt-concrete in good condition	Good condition-coating subjected to construction traffic
4-3	CIB	3	1966	Very slight gen. random cracking v.s. holes at cracks near open drain	Moderate transverse cracking and wet efflorescence between beams
			1965	Asphalt-concrete in good condition	Good condition-no leaks
4-4	CIB	3	1966	Slight long. and random cracking at lane joints and main traffic area	No Defects

CONDITION SURVEYS OF PROTECTIVE COATINGS

BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Cracks in asphalt-concrete adjacent to expansion joints	Good Condition - No leaks
4-5A E.B.	CIB	3	1966	No Defects	No Defects
			1965	Asphalt-concrete in good condition	Good Condition - No leaks
4-5B W.B.	CIB	3	1966	No Defects	No Defects
			1965	Asphalt-concrete in good condition	Good Condition - No leaks
4-6	CIB	3	1966	Moderate long. and random cracking at lane joints and traffic lane. A.C. patching at pier slight.	No Defects
			1965	Transverse cracks in asphalt-concrete at bridge joints.	Cracks with leakage and efflorescence
4-7	PCTB	5	1966	Moderate severe long. trans. cracking over piers and A.C. patching-traffic lanes	slight to moderate severe moisture effl. and cracking between beams
			1965	Longitudinal cracks in asphalt-concrete	Good Condition - No leaks
4-8A E.B.	CIB	5	1966	Slight wetness at lane joints	No Defects
			1965	Alligator cracking of asphalt-concrete	Good Condition - No leaks
4-8B W.B.	CIB	5	1966	Slight long. and random cracking at lane joints	No Defects
			1965	Fine alligator cracks in northbound lane	Good Condition - No leaks
4-9	CPLG	5	1966	Moderate longitudinal cracking at mall joints	No Defects (not open)

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Asphalt concrete in good condition	Good condition - no leaks
4-10	CIB	5	1966	Slight long. trans. cracking at abutments	No defects
			1965	A few small cracks in asphalt concrete near transverse joints	Good condition - no leaks
4-11	CIB	5	1966	Slight long. cracking at A.C. joints-dip in span 2 - 1st lane	No defects
			1965	Numerous fine cracks in asphalt concrete surface	Good condition - no leaks
4-12	CPLG	5	1966	Slight long. and random cracking at lane joints-ponding west side	No defects
			1965	Asphalt concrete in good condition	Good condition - no leaks
4-13	CIB	5	1966	No defects	No defects
			1965	Longitudinal cracks in asphalt concrete	Good condition - no leaks
4-14	CIB	5	1966	Very slight long. cracking at A.C. joint	No Defects
4-15	PCBB	5	1966	No defects	No defects
4-16	PCBB	5	1966	No defects	No defects
			1965	Bleeding noted through asphalt-concrete	S.I.P. forms - good condition
5-1	CIB	3	1966	Bubble in A.C. (rain-hard to determine)	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-2	CPLG	3	1966	No defects	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-3A N.B.	CIB	3	1966	All joints deteriorated except south at abutment	No defects

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-3B S.B.	CIB	3	1966	No defects	Moist and rusting-1 spot near open pipe drain
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-4A N.B.	CIB	3	1966	Very slight cracking (transv.) in main traffic area-ponding- n. abut.	No defects
			1965	Several patched areas on asphalt concrete	S.I.P. forms - good condition
5-4B S.B.	CIB	3	1966	Ponding at north abutment	No defects
			1965	Alligator cracking in asphalt-concrete along curb	S.I.P. forms - good condition
5-5	CIB	4	1966	Pothole at N. joint - no defects	No defects (some rusting-drains)
			1965	Asphalt concrete in good condition	Several small cracks - no leaks
5-6A N.B.	Rigid Frame	4	1966	Mod. severe crack over abutment	No defects
			1965	Asphalt concrete in good condition	Several small cracks - no leaks
5-6B S.B.	Rigid Frame	4	1966	Mod. severe crack over pier (transverse)	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-7A N.B.	CIB	4	1966	No defects	No defects
			1965	Several patched areas on asphalt concrete	S.I.P. forms - good condition
5-7B S.B.	CIB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-8	CIB	4	1966	No defects	Rust over first pier

CONDITION SURVEYS OF PROTECTIVE COATINGS

BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) At Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
5-9	CIB	3	1965	Asphalt concrete in good condition	S.I.P. forms - black discoloration on forms
			1965	Hairline cracking of asphalt concrete in S.B. lane	Slight leakage between beams. Beams out of alignment
5-10	PCBB	4	1966	No defects	Brown stains showing on bottom of beams
			1965	Asphalt concrete in good condition	No leakage noted
5-11	CIB	4	1966	1 Crack over pier	No defects
			1965	Resurfaced with asphalt concrete in 1964 - Good condition	No leakage noted
5-16	CIB & CPLG	4	1966	No defects	Slight rusting along beams near open grating
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-17	CIB	4	1966	No defects	Mod. S.I.P. rusting pier caps
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
5-18	CIB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	Cracks and efflorescence near open grating
6-1A N.B.	CIB	5	1966	No defects	Slight cracking & effl. between beams
			1965	Asphalt concrete in good condition	No leakage noted
6-1B S.B.	CIB	5	1966	Deterioration at expansion jts. - some popouts	No defects
			1965	Asphalt concrete deterioration at west end. Bleeding noted	Cracks and efflorescence near open grating
7-1	CIB	4	1966	No defects	Mod. moisture and effl. near drains - SL transv. cracks between beams

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Asphalt concrete deteriorated at north end	S.I.P. forms - good condition
7-2A N.B.	CPLG	4	1966	No defects	No defects
			1965	Asphalt concrete deteriorated at north end	S.I.P. forms - good condition
7-2B S.B.	CPLG	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	Leakage and efflorescence between all beams
7-3A N.B.	PTB	4	1966	No defects	Crack and effl. - open drains - effl. between T Beams
			1965	Asphalt in good condition	Leakage and efflorescence between all beams
7-3B S.B.	PTB	4	1966	No defects	Mod. effl. between T Beam
			1965	Asphalt concrete in good condition	Moderate leakage between beams
7-4A N.B.	PTB	4	1966	No defects	Cracks and leakage adjacent to open drains - effl. between beams
			1965	Asphalt concrete in good condition	Moderate leakage between beams
7-4B S.B.	PTB	4	1966	No defects	Cracks and leakage adjacent to open drains - effl. between beams
			1965	Longitudinal crack in asphalt-concrete	Moderate to heavy leakage between beams
7-5	PTB	4	1966	No defects	Rusting on pier caps - cracks and effl. and ostalactities - open drains - effl. betw. beams
			1965	Asphalt concrete in good condition	Good condition - no leaks
7-6A N.B.	PCBB	4	1966	Slight general transverse cracking over pier caps	Slight leakage between beams
7-6B S.B.	PCBB	4	1966	Slight general transverse cracking over pier caps	Slight leakage between beams

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Asphalt concrete in good condition	Good condition - no leaks
7-7A N.B.	PCBB	4	1966	Cracked over pier caps only	Slight leakage between beams (wet)
7-7B S.B.	PCBB	6	1966	Cracked over pier caps only	Slight leakage between beams (wet)
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
7-8A N.B.	CWFB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
7-8B S.B.	CWFB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	No leaks detected in 1965. Slight leakage in 1963 and 1964
7-9	PCBB	4	1966	Cracks at joints over pier caps	Slight moisture between box beams
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
7-10A N.B.	CWFB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
7-10B S.B.	CWFB	4	1966	No defects	No defects
			1965	Asphalt concrete cracked over piers	Moderate leakage between beams
7-11	PCBB	4	1966	Joint cracking over pier caps	2 or 3 small moist areas between box beams
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
7-12	CIB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	Good condition - no leaks
7-13	CIB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	Good condition - no leaks
8-1	CWFB	4	1966	No defects	No defects

CONDITION SURVEYS OF PROTECTIVE COATINGS

BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Asphalt concrete in good condition	Leakage and efflorescence at diagonal cracks from corners of open grating
8-2	CPLG	4	1966	No defects	Cracks at open drains showing moisture and efflorescence
			1965	Asphalt concrete in good condition	Good condition - no leaks
8-3A E.B.	CWFB	4	1966	No defects	No defects
			1965	Asphalt concrete in good condition	Good condition - no leaks
8-3B W.B.	CWFB	4	1966	No defects	No defects
			1965	No comments	Efflorescence probably from dam underneath
8-4	Conc. Arch	5	1966	Slight transverse cracks over piers	Effl. due to water spray from dam
			1965	Asphalt concrete in good condition	Good condition - no leaks
8-5	CWFB	5	1966	No defects	No defects
			1965	Diagonal cracks in asphalt concrete at open grating	S.I.P. forms - good condition
9-1	CIB	4	1966	Mod. brown stains at random-mod. diag. cracks at open drains	No defects
			1965	Asphalt concrete deteriorated near bridge piers	S.I.P. forms - good condition
9-2A N.B.	CIB	4	1966	Mod. long. and trav. cracking at lane joints and main traffic area	Mod. severe effl. and rust-pier caps and between beams
			1965	Asphalt concrete in good condition	S.I.P. forms - good condition
9-2B S.B.	CIB	4	1966	Spalling at span joints	No defects (possible leakage)
			1965	Asphalt concrete patched-longitudinal cracking	S.I.P. forms - good condition
9-3	WPIG	4	1966	Severe cracking, deep holes, patching at abutments and traffic area	No defects

CONDITION SURVEYS OF PROTECTIVE COATINGS
BRIDGES WITH POLYESTER RESIN LAMINAR MEMBRANES

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Diagonal cracks in asphalt concrete at open grating	S.I.P. forms - good condition (not open to traffic)
9-4	CIB	4	1966	No defects	No defects
			1965	Bleeding noted through asphalt concrete	S.I.P. forms - good condition (not open to traffic)
9-5A N.B.	CIB	4	1966	No defects	No defects
			1965	Bleeding noted through asphalt concrete	S.I.P. forms - good condition (not open to traffic)
9-5B S.B.	CIB	4	1966	Mod. A.C. patch at pier-slight diag. cracks at open drains	No defects
			1965	Bleeding noted through asphalt concrete	S.I.P. forms - good condition (not open to traffic)
9-6A S.B.	CIB	4	1966	Water leaking from A.C. patching-severe	No defects
			1965	Bleeding noted through asphalt concrete	S.I.P. forms - good condition (not open to traffic)
9-6B N.S.	CIB	4	1966	Mod. diag. cracking at open drains- patching at open drains	No defects
			1965	Asphalt concrete in good condition	Transverse crack near location of header beam
9-8	CIB	4	1966	No defects	Mod. transv. cracks at abutments
			1965	Asphalt concrete in good condition	Diagonal crack near header beam and scupper
9-9	CIB	4	1966	No defects	Mod. transv. cracks at abutments
			1965	Asphalt concrete worn exposing coating in spots	Transverse cracks with efflorescence
9-10	WPIG	4	1966	Mod. patching at skewed joints	Mod. severe transv. cracking between beams

BRIDGES WITH BITUMINIZED EPOXY (A) - SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Coating applied to structure constructed in 1954. Coating badly delaminated and cracked.	Underside badly spalled and cracked with heavy leakage in 1964. Not inspected in 1965
4-22	PLG	6	1966	Many patched areas in poor condition	Leakage-wet-effl.-under all spans between beams
			1965	Surface worn with most of abrasive material missing. Patched areas & some cracking noted.	Good condition - no leaks
4-23	CIB	6	1966	Long.-trans.-fine and random cracking moderate	Transv. and diag. cracks near drains-spalls-moderate.
4-24	CIB	5	1965	Good condition - no deterioration	Good condition - no leaks
			1965	Random cracking, wear, some delamination of coating	Good condition - no leaks
4-25	CIB	6	1966	Long. trans. diag. and random cracking all over-mod. sev.	Mod. effl. betwen beams
			1965	Badly delaminated, no bond at delaminations of coating	Good condition in 1964. Not inspected in 1965
4-37	CIB	7	1966	Severe general loss of bond W.C. to coating	No defects
			1965	Cracking throughout-some delamination near gutters	Transverse cracks and efflorescence
4-40	CIB	6	1966	Long. transv. general cracking-mod.severe loss of bond, coating to base	Mod. trans. cracks-moist and effl. between beams
			1965	Random cracking throughout the surface	Some cracks with efflorescence
4-41	CIB	6	1966	Mod. severe long. and transv. and random cracking-general	Effl. rusting, trans. cracking-between beams-slight
			1965	Random cracking throughout the surface	Slight cracking and efflorescence
4-42	CIB	6	1966	General random, diag. and transv. cracking mod. severe	No defects

BRIDGES WITH BITUMINIZED EPOXY (A) - SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Random cracking - concrete patch at transv. joint	One large spalled moist area, cracks and efflorescence
4-43	CIB	6	1966	Delamination-random cracking-traffic area curb-mod. severe	Moderate effl. between beams
			1965	Random alligator cracking near curb. Longitudinal crack at center	Good condition - no leaks
4-44	CIB	6	1966	General random cracking (transv.) moderate	No defects
			1965	Random alligator cracking and crack at longitudinal joint	Rust and two small moist areas evident in S.B. lane
4-45	CIB	6	1966	Long. transv. random cracking all over - moderate	Very slight effl. between beams
			1965	Some alligator cracks along curb areas	S.I.P. forms - one rust spot over pier
4-46	CIB	5	1966	(resurfaced) no defects	1 area near S. pier cap badly rusted
			1965	Map cracking throughout. Delamination along curb areas	Mostly inaccessible, where noted, beams were rusted
4-47	CIB	4	1966	Entire bridge is cracked trans., long. and random-patched area	Inaccessible
			1965	Map cracking throughout. Bad cracking around joints	Many longitudinal cracks with efflorescence noted at random. A few transv. cracks
4-48	CIB	4	1966	General long. trav. random cracking - severe	Severe leakage and cracks - entire
			1965	Cracking, checking, delamination, potholes and patching	Many large cracks with much efflorescence
4-50	Libbed Arch	5	1966	Delamination-potholes-cracking over entire bridge	Leakage, spalls and abutments cracked-generally in bad shape

BRIDGES WITH BITUMINZED - EPOXY (A) LAMINAR MEMBRANE

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Asphalt concrete in good condition	Good condition - no leaks
4-27	CIB	5	1966	No defects	No defects
			1965	Asphalt concrete in good condition in 1965 Removed a small section of asphalt concrete in 1963 - coating in good condition	Not inspected in 1965 - Good condition in 1963
4-283 W.B.	CIB	5	1966	Deep holes - loss of bond - test sampling slight	Not noted
			1965	Asphalt concrete in good condition in 1965 removal of pavement in 1963 indicated poor bonding of coating to concrete	Good condition - no leaks under coated area
4-29A N.B.	CIB	5	1966	No defects	Moist between beams - gen. transv. cracking-moderate
			1965	Asphalt concrete in good condition in 1965 removal of pavement in 1963 indicated no bond between coating and concrete	Good condition - no leaks under coated area
4-293 S.B.	CIB	5	1966	No defects	Moist between beams - gen. transv. cracking-moderate
			1965	Asphalt concrete in good condition except for one patch. Inspection in 1963 indicated pinholing and peeling of resin coating	S.I.P. forms - good condition - no leaks
4-30	CIB	5	1966	Popouts at abutments - moderate	No defects
			1965	Asphalt concrete cracked over one pier in 1965. Inspection in 1963 indicated no bond of coating to concrete	S.I.P. forms - good condition - no leaks
4-31	CIB	5	1966	Mod. long., transv., diag. cracking at pier cap, between beams joints skewed	No defects
			1965	Asphalt concrete in good condition	Good condition - no leaks
4-38	CIB	5	1966	No defects	(Moist at mall joint) no defects
			1965	Two small patches in asphalt concrete wearing surface	Good condition - no leaks

BRIDGES WITH BITUMINZED - EPOXY (A) LAMINAR MEMBRANE

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
4-39	CIB	5	1966	No defects (2 sm. patches)	No defects

BRIDGES WITH BITUMINIZED EPOXY (A) - SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Delamination at joints - some shrinkage cracks	Good condition - no leaks
4-51	CIB	6	1966	Moderate general transv. and random cracking	No defects
5-12	CIB	6	1966	Sev. cracking - holes patches	Moderate leakage and cracks between beams
			1965	Satisfactory except for a few small spalls at transverse joints	No observation made
10-1	CIB	4	1966	Wear-some bond loss	No defects
			1965	Satisfactory except for a few small spalls at transverse joints	No observation made
10-2	CIB	4	1966	Grain wear, coating in good shape	No defects
4-20	CIB	4	1965	Good condition after 1 yr. Some coating loss after 2 yrs. Resurfaced in 1965	Map cracking, efflorescence and several large transverse cracks.

BRIDGES WITH EPOXY - RESIN SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Cracks, wear and bond failure noted in delamination	Good condition - no leaks
4-21	CIB	6	1966	General loss of bond-coating to base-severe	No defects
			1965	Coating on bridge sidewalks only. Some poorly bonded areas.	Good condition - no leaks
4-23	CIB	6	1966	Long., trans., fine and random cracking-mainly E.B. lane-mod.	Mod. cracking, moisture and effl. near drains.
			1965	Some wear of coating. Good bond to concrete deck, signs of transverse cracking beneath surface, but not through coating.	Good condition - no leaks
4-49	CPLG	2	1966	Worn away at patches	Effl. along fascia beams

BRIDGES WITH BITUMINIZED EPOXY (B) - SURFACE OVERLAY

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Coating applied to structure built in 1949. One delaminated area 1 1/2'x2 1/2'. Transverse and longitudinal cracking at joints. Cracks along edges and near open drains.	Unable to inspect
4-33	PLG	2	1966	Mod. long. and transv. cracking at lane joints	No defects
			1965	Coating applied to structure built in 1952. Full length cracking at longitudinal joints.	Unable to inspect
4-34	Conc. Box	2	1966	Mod. long. and transv. cracking at lane joints	Not noted
			1965	Coating applied to structure built in 1952. No defects noted on surface	Leakage and efflorescence in one localized area.
4-35	CWFB	2	1966	Slight long. and transv. cracking at lane joints	No defects
			1965	Coating applied to structure built in 1952. One long diagonal crack at west end of W.B. lane. Full length cracks over longitudinal joint	Unable to inspect
4-36	CWFB	2	1966	Long., transv., diag. cracking in general-slight	No defects
9-13	CIB	1	1966	Some holes (bond failure) some with concrete loss (not adhesive failure)	Not noted

BRIDGES WITH MODIFIED ASPHALT CUTBACK LAMINAR MEMBRANE

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks	
				Wearing Surface	Underside
			1965	Asphalt concrete coated with Guardkote 140 inspection in 1965 indicated wear and cracking of Guardkote 140, removal of a section of asphalt concrete in 1963 indicated no bond between item 363 and concrete deck	Good condition - no leaks
4-23	CIB	6	1966	Long. trans., find and random cracking-mod. E.B. Lane	Transv. and diag. cracks near drains-spalls moderate
			1965	Asphalt concrete coated with Guardkote 140 wearing surface. Random cracking and bond-failure of Guardkote 140 to asphalt concrete. Removal of a 2'x2' section of asphalt concrete in 1963 indicated no bond of item 361 to concrete deck.	Good condition - no leaks
4-25	CIB	6	1966	Long. trans., diag. and random cracking-entire bridge-mod., severe	Slight eff. between beams
			1965	Asphalt concrete in good condition in 1965. Removal of a 2'x2' section of asphalt concrete in 1963 indicated item 361 poorly bonded to concrete.	Good condition - no leaks
4-26	CIB	6	1966	No defects	Very slight transverse cracking between beams
			1965	One small pothole and shoving in asphalt concrete in 1965. Removal of small section of asphalt concrete in 1963, indicated no bond between item 363 and concrete deck.	Not inspected in 1965. Good condition in 1963
4-28A E.B.	CPG	6	1966	General, [illegible] cracking-moderate	No defects

BRIDGES WITH PETROLEUM DISTILLATE OIL SURFACE TREATMENT

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Large deteriorated area on south end considerable transverse cracking throughout	Transverse cracking with efflorescence
5-13A	CIB	10	1966	Mod. deepholes A.C. patches general-spalling and cracking	Mod. severe general transverse cracking

BRIDGES WITH SILICONE SURFACE TREATMENT

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
			1965	Asphalt concrete on deck shows little deterioration. Some scaling of sidewalk and curbs	Wet spots and small cracks under fascia beams.
1-17	CPLG	9	1966	Occasional sm. potholes - no defects	Small cracks and effl. between fascia and 1st beam - each side
			1965	Asphalt concrete in good condition. Light scaling on sidewalks and curbing	Good condition - no leakage
1-19	CIB	10	1966	Some worn spots in coating - no defects	No defects
2-3	CIB	?	1966	Mod. severe general cracks, spalls and popout	Not noted
			1965	Surface scaled	Evidence of leakage and some spalling
2-4	CIB	9	1966	A.C. patching at lane joints-scaling on deck	Slight effl. and rusting at pier caps
			1965	Recently applied asphalt concrete wearing surface	Evidence of heavy leakage from stains
2-5	CIB	9	1966	Slight transverse cracking at lane joints	Severe map cracking-effl.-stalactites-cores removed and not patched
			1965	Several popouts, scaling and small cracks	Small wet areas near fascia beams
2-6	CIB	9	1966	Slight transv. cracking at lane joints and scaling	Mod. effl. and transv. cracking at abutments-stalactites
			1965	Cracking, scaling and patching noted on surface	Signs of scaling at northend
2-7	CIB	9	1966	Mod. severe transv. cracking-main traffic lanes-spalls and patches	Slight random cracking-map cracking and effl. at northend Gnrl.
			1965	Cracking, scaling and many patches on surface	Evidence of leakage and cracks with effl.
2-8	WPLG	9	1966	General random cracking mod. sev.-C.C.-A.C. and random patching	Mod. effl. and trav. cracks-between beams
			1965	Considerable map cracking, popouts and transverse cracks. Sidewalks pitted badly.	Numerous transverse cracks with efflorescence

BRIDGES WITH SILICONE SURFACE TREATMENT

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
4-32	CIB	10	1966	Popouts and map cracking	Stalagtites-wet-effl. cracks on ends near abuts.
			1965	Spalling and cracking of portland cement concrete	Transverse cracking with leakage and effl.
5-13B S.B.	CIB	10	1966	Mod. sev. general transverse cracking	Mod. general transverse cracking
			1965	Spalled, cracked and patched	Scaled, spalled and leakage
6-2	CIB	10	1965	Severe general cracking and patching-random	Severe effl. and stalagtites-severe general random cracking
			1965	Resurfaced recently with asphalt concrete. Popouts on sidewalks	A few small transverse cracks with effl.
6-3	CIB	10	1966	No defects	Effl. and transverse cracks between beams-slight
			1965	Resurfaced recently with asphalt concrete Popouts on sidewalks	One small crack with efflorescence
6-4	CIB	10	1966	No defects	Effl. and transverse cracks between beams-slight
7-14	WPLG	10	1966	Mod. transv. cracks-traffic lanes-general popouts-moderate	No defects
			1965	Asphalt concrete had one pothole. Side-walks has hairline cracks and popouts	Damp spot at south end, otherwise in good condition
7-15	PLG	10	1966	No defects (resurfaced)	Not noted
			1965	Asphalt concrete in good condition. Side-walks in good condition	Good condition - no leaks
7-16	WPLG	7	1966	Cracks and popouts-long. cracks at lane joints	No defects
9-3	CIB	9	1966	Diagonal cracks at corners	Same as last report-leakage, effl, cracks, spalling, scaling
			1965	Transverse cracking and scaling on deck	Cracks, spalling, scaling, effl. and stalactites

BRIDGES WITH LINSEED OIL SURFACE TREATMENT EXPERIMENTAL

Bridge No.	Design	Age (Yrs.) Last Inspection	Surveys	Remarks: Wearing Surface	Remarks: Underside
—	CIB	3	1965	Test installation on roadway sections near bridge on bridge curbing and bridge sidewalks. Untreated and treated sections both evaluated. Little scaling noted on either untreated and treated sections. More popouts noted in untreated sections after first year.	
1-18	Ribbed Conc. Arch	2	1965	Treatment on bridge sidewalks only. Hairline cracks noted in sidewalks, may have been evident before treatment was applied.	Inaccessible
—	PBB	2	1965	Sidewalks and walls were only treated areas, were in good condition.	Good condition under treated area

BRIDGE WITH NEOPRENE-HYPALON RUBBER SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks: Wearing Surface	Remarks: Underside
1-2	CIB	1963	1967	An experimental patch 18'x14' applied in July 1963. Bubbles developed in coating, one week after application. Deterioration started at a bubble and noted in April 1964. Inspection in 1965 indicated 3'x1" section removed by traffic. Practically gone after 4 years.	Good condition

BRIDGES WITH SILICONE RUBBER SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks: Wearing Surface	Remarks: Underside
1-20	CIB	July 1964	1967	Experimental patch 14'x16' applied during 1964 in passing lane. Generally good for 2 yrs. Rapid deterioration due to wear after 2 yrs. Practically removed, last inspection 1967.	Good condition
1-26	CIB	Sept. 1965	1967	Experimental coating applied to 1932 sq. ft. in curb lane. Deterioration started within one week over entire structure except north span. Deterioration started north span approx. 1 mo. 50% coating loss in less than 6 mos. Failure due to poor bond attributed to inadequate surface preparation.	Good condition
1-26A	CIB	Sept. 1966	1967	Slight deterioration noted after 1 mo. Definite deterioration after 2 mos. Practically no material remaining.	Good condition

BRIDGE WITH POLYESTER RESIN W/O FIBERGLASS SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks	
				Wearing Surface	Underside
1-25	CIB	Oct. 1965	1967	Coating applied to 2160 sq. ft in curb lane of bridge. Good condition for 14 mos. After 14 mos. slight deterioration noted. Gradual increase in deterioration during 1967 with approx. 40% loss of coating after 2 yrs.	Good condition

BRIDGE WITH FLEXIBLE POLYESTER RESIN SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks	
				Wearing Surface	Underside
1-31	CIB	Sept. 1967	1968	After 5 mos., coating is in good condition., 1968 inspection.	Good condition

BRIDGE WITH POLYURETHANE RESIN (HIGH TEMP.) SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks	
				Wearing Surface	Underside
1-28	CIB	Oct. 1965	1967	Coating applied to 2160 sq. ft. in curb lane of bridge. Deterioration started after approx. 6 wks. 20% loss after 3 mos. Gradual increase over 50% loss when last inspected in 1967.	Good condition

BRIDGE WITH STABILIZED RUBBER VINYL PITCH SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks: Wearing Surface	Remarks: Underside
1-27	CIB	Oct. 1965	1967	Coating applied to 2442 sq. ft. in curb lane of bridge. Deterioration started after approx. 3 wks. Approx. 90% of coating gone within 6 mos. Poor bond was attributed to low temperatures during application and inadequate surface preparation.	Good condition

BRIDGES WITH LATEX-MORTAR SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks	
				Wearing Surface	Underside
4-17	CPG	1958	1963	Coating deteriorated when inspected in 1963. Resurfaced in 1964.	Leakage and transverse cracking
4-18	CIB	1958-1961	1963	Coating deteriorated when inspected in 1963. Resurfaced in 1964.	Leakage and transverse cracking
4-19	CIB	1958-1961	1964	Bad cracking, coating loss in 1964. Resurfaced in 1965.	Leakage and transverse cracking

BRIDGE WITH URETHANE-MORTAR SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks	
				Wearing Surface	Underside
4-20	CIB	1961	1964	Bubbles formed during cure. Coating failures noted within 1 mo. Badly deteriorated after 2 yrs. Resurfaced in 1965.	Leakage, cracking

BRIDGE WITH EPOXY - POLYSULFIDE SURFACE OVERLAY

Bridge No.	Design	Placed Date	Last Inspection	Remarks: Wearing Surface	Remarks: Underside
1-32	CIB	Oct. 1967	1968	After 5 mos., coating is in good condition, 1968 inspection.	Good condition